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THE STRAWBERRY ROOTWORM, A NEW PEST ON GREENHOUSE ROSE

DISSERTATION

PRESENTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY IN THE GRADUATE SCHOOL OF THE OHIO STATE UNIVERSITY

BY

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The Ohio State University

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THE STRAWBERRY ROOTWORM, A NEW PEST ON GREENHOUSE ROSES[1]

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During the last 40 years the native insect known as the strawberry rootworm, or strawberry leaf beetle, *Paria canella* (Fab.), varieties *quadrinotata* (Say) and *gilvipes* (Crotch), was considered a serious enemy of strawberry, raspberry, and a few other plants only. Suddenly this little beetle appeared in greenhouses, attacking roses in Virginia, Indiana, New Jersey, Pennsylvania, and Maryland. Prior to 1916 a suggestion that this insect would abandon its usual hosts (*29, p. 67*)[2] for the succulent rose might have been subject to considerable doubt; but when simultaneous reports were received by the Bureau of Entomology concerning two widely separated infestations of an insect injuring roses in greenhouses at Alexandria, Va., and Richmond, Ind., such doubts would have been dispelled, because an examination of the specimens which accompanied

[1] The account of the strawberry rootworm and its control contained in this bulletin is the result of an investigation started in July, 1919, when the first reports were received by the Bureau of Entomology concerning injury by this insect to greenhouse roses. E. L. Chambers assisted in the work until August, 1920, and C. F. Doucette from January, 1921, until it was completed. Through the courtesy of J. G. Sanders, then director of the bureau of plant industry, Pennsylvania Department of Agriculture, a large portion of the work was done in cooperation with that bureau with headquarters at Doylestown, Pa. Credit is due J. K. Primm and A. W. Buckman, of the Pennsylvania Bureau of Plant Industry, and also Miss B. M. Broadbent and A. T. Grimes, of the Bureau of Entomology, for the assistance which they rendered at intervals in the work. Figures 3, 4, 7, 8, and 9 were prepared by Miss Aimé Motter. Special thanks are accorded to John A. Andre, of Doylestown, for providing laboratory space, plants, and facilities for carrying on the work, as well as to other florists who offered assistance. The writer is also indebted to Prof. Herbert Osborn, of Ohio State University, for his interest, advice, and encouragement throughout the progress of the work. Acknowledgment is given to Dr. A. L. Quaintance and E. R. Sasscer, of the Bureau of Entomology, for their many valuable suggestions.

[2] Figures in italics in parentheses refer to "Literature cited," p. 47.

these reports proved them to be the chrysomelid beetle referred to above. Unfortunately the name "strawberry rootworm" does not imply that the greenhouse rose is a host or food plant, but in view of its long standing this name must be retained.

An investigation of these reports revealed the seriousness of the situation and indicated that the rose-growing industry was confronted with another important problem. Moreover, according to their statements, the florists were unable to check the ravages of these beetles by the use of measures ordinarily employed for controlling leaf-feeding insects. A review of the available literature on this species indicated that little was known of its life history and habits under greenhouse conditions. Naturally, owing to the change from the normal temperate climate out of doors to the subtropical conditions prevailing under glass, and to the intensive and specialized culture of the rose, important differences in biology and control would result.

The data collected during the last three years of research on the biology and control of this insect under conditions which exist in commercial greenhouses are presented in this publication.

SYSTEMATIC HISTORY

The two forms of the strawberry rootworm beetle encountered in the greenhouse and covered by these investigations appear to be *Paria canella quadrinotata* (Say) and *P. canella gilvipes* (Crotch), but so much conflict of opinion is apparent among various authorities who have published upon this group of beetles that the status of these varieties or species is still a matter of conjecture. The following discussion relates to the changes in nomenclature of these two varieties only.

The first name applied to this group of forms was *Cryptocephalus canellus*, given by Fabricius (*9*, *p. 52*) in 1801. Seven years later this was changed to *Eumolpus canellus* by Olivier (*22*, *p. 914*). In 1824 Thomas Say (*26*, *p. 446*) first described as *Colaspis quadrinotata* the four-spotted form here treated. In 1858 LeConte (*20*, *p. 86*) erected the genus Paria for five species, including *canella* and *quadrinotata*. In 1873 Crotch (*7*, *pp. 33*, *39*), in revising the North American eumolpids, distinguished the genera Typophorus and Paria and placed *quadrinotata* (misprinted "*6-notata*") and *gilvipes* as varieties of *Paria sexnotata* Say. In 1882 Jacoby (*18*, *p. 182*) mentioned Paria as very closely related to Typophorus, but kept the two genera separate. In 1884 Forbes (*13*, *p. 159*) in his economic treatise associated *quadrinotata* and *gilvipes* as synonymous with *Paria sexnotata* Say.

In 1892 Paria and Typophorus were united by Horn (*16*, *p. 208*), in his monograph on the Eumolpini of Boreal America, under the older name Typophorus. He listed *canellus* as one of the two included species and reduced all of the other specific names used under Paria to the rank of varieties or synonyms under *canellus*, in which he placed *quadrinotatus* as a variety, and *gilvipes* as a subvariety of the variety *aterrimus* Oliv. In 1910 Blatchley (*2*, *p. 1139*), in his Coleoptera of Indiana, followed Horn's nomenclature for the forms above mentioned. In 1914 Clavareau (*4*, *pp. 153–157*) catalogued

Paria and Typophorus as separate genera, with *canella*, *quadrinotata*, and *gilvipes* as distinct species of Paria, and in 1920 Leng (*21, p. 294*) also separated the two genera, but listed only the one species *canella* under Paria with *gilvipes* and *quadrinotata* as two of the nine varieties of the species. The writer has followed Leng's use of the names.

The synonymy of *Paria canella quadrinotata* (Say) appears, therefore, to be as follows:

1824. *Colaspis quadrinotata* Say (*26, p. 446*).
1858. *Paria quadrinotata* (Say) LeConte (*20, p. 86*).
1873. *Paria sexnotata quadrinotata* (Say) Crotch (*7, p. 39*).
1892. *Typophorus canellus quadrinotatus* (Say) Horn (*16, p. 208*).
1914. *Paria quadrinotata* (Say) Clavareau (*4, p. 156*).
1920. *Paria canella quadrinotata* (Say) Leng (*21, p. 294*).

The synonymy of *P. canella gilvipes* (Crotch) appears to be as follows:

1833. *Metachroma gilvipes* Dejean (nomen nudum) (*8, p. 412.*)
1873. *Paria sexnotata gilvipes* (Dejean) Crotch (*7, p. 39*).
1892. *Typophorus canellus aterrimus gilvipes* (Crotch) Horn (*16, p. 208*).
1914. *Paria gilvipes* (Crotch) Clavareau (*4, p. 156*).
1920. *Paria canella gilvipes* (Crotch) Leng (*21, p. 294*).

ECONOMIC HISTORY AND FOOD PLANTS[3]

Cook (*5*), in a paper read in 1880 and published in 1881, seems to have been the first to mention the four-spotted Paria as injurious to strawberry. Since then a number of accounts have referred to the insect as a strawberry pest. Strawberry, raspberry, juniper, wild crab apple, and cinquefoil are mentioned as hosts of the adults by Forbes (*13, p. 169*) in 1884. In 1893 Webster (*28, p. 202*) "observed them in Ohio eating holes in the leaves of blackberry and raspberry." Injury to raspberry is recorded in Canada by Fletcher (*11, p. 81; 12, p. 216*) in 1894 and 1895, and in Maine by Harvey (*15, pp. 106–110*) in 1896.

In correspondence received by the Bureau of Entomology on May 10, 1905, from Rutland, Md., it was stated that the foliage of Prairie and Harrison rose plants was being perforated by beetles. The specimens were probably *Typophorus canellus* but because of their crushed condition the determination was not positive.

Felt (*10, p. 537*) records butternut, mountain ash, and heath aster (*Aster ericoides*) as hosts. According to Swenk (*27, p. 83, pl. 3, b*) thousands of the beetles were found feeding voraciously in an apple orchard in Nebraska. Neither of these references associates any particular variety of *Paria canella* with these hosts. The variety *sexnotata* is recorded on juniper by Say (*26, p. 446*) in 1824.

Black walnut buds were reported as being injured by specimens received by the Bureau of Entomology in April, 1921, from Ithaca, N. Y., and determined[4] as *Paria canella* Fab. In the same month Britton (*3, p. 195*) reported injury on the tender terminal leaves of Japanese walnut by adults of the varieties *gilvipes* and *quadrinotata* at Wilton, Conn. In July, 1921, J. K. Primm found adults of the variety *gilvipes* feeding on leaves of butternut in a nursery at West

[3] Because of the confusion in the varietal nomenclature, it has been difficult in many cases to decide whether references to the species *Paria canella* refer to *quadrinotata* or to *gilvipes*. Where a description was given which corresponded with the characters of either of these varieties, the reference has been cited.

[4] Determined by E. A. Schwarz, Bureau of Entomology.

Chester, Pa. Grapes, oats, rye, millet heads, peach, and apple are reported as hosts in correspondence from State entomologists.

The earliest published record of its occurrence under glass is by Cory (*6, p. 206*), who reported that "it was found injuring a rose planting in the establishment of a Baltimore florist," during 1916. Specimens received by the Bureau of Entomology which bear the date of October 28, 1916, were taken from rose by R. E. Snodgrass, at Indianapolis, Ind. Specimens now in the Indiana State collection were obtained in greenhouses at Cumberland on November 8, 1916, and H. F. Dietz collected beetles in the same greenhouses on December 5, 1917. Peterson (*23, p. 468*) reports severe injury in a greenhouse in New Jersey in 1917.

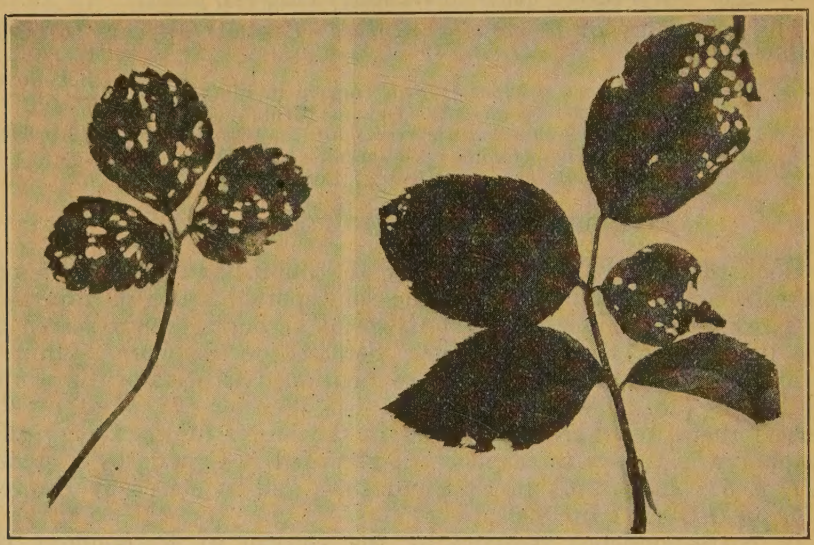

FIG. 1.—The "shot-hole" punctures characteristic of the feeding of adults of the strawberry rootworm on strawberry and rose foliage

A number of other reports which relate to its occurrence in greenhouses have been published within the last three years, but no earlier records have been found.

To sum up the foregoing reports and records, the following may be listed as food plants:

Amygdalus persica	Peach.
Aster ericoides	Heath aster.
Avena sativa	Oats.
Chaetochloa italica	Millet.
Fragaria spp	Strawberry.
Juglans cinerea	Butternut.
Juglans nigra	Black walnut.
Juglans sieboldiana	Japanese walnut.
Juniperus spp	Juniper.
Malus spp	Wild crab.
Malus sylvestris	Apple.
Potentilla spp	Cinquefoil.
Rosa spp	Rose.
Rubus spp	Raspberry, blackberry.
Secale cereale	Rye.
Sorbus spp	Mountain ash.
Vitis spp	Grape.

RECENT INJURY IN GREENHOUSES

In 1919, shortly after receipt of the reports concerning the infestations in Virginia and Indiana, a visit to the one in Alexandria,

Va., on July 25 revealed the seriousness of the injury and the reason for the appeal for assistance. The stock in eight large houses suffered infestation, five, of the open-range type, being extremely heavily infested. The damage was caused mainly by the adults, which were present in unusually large numbers. As a result of their voracious feeding practically all of the foliage was badly perforated and ragged (fig. 1). In addition, a large proportion of the young shoots had the wood badly scarred and girdled, giving it a very unsightly appearance. It was found that the adults had a marked preference for this new wood, of which there was an abundance at this particular season, owing to the fact that the roses were being forced vigorously. Further examination showed that the larvæ had also been feeding on the roots (fig. 2) earlier in the season. As a result of these injuries a gradual killing of the affected parts ensued, producing a stunted growth of the plants. In attempting to establish the possible origin of the infestation in Alexandria, records by A. D. Borden showed that this insect had been attacking roses in the same houses three years previously. Recent evidence disclosed that the soil in which the roses were growing had been in the benches since then; hence it seems that their occurence dated back to that time.

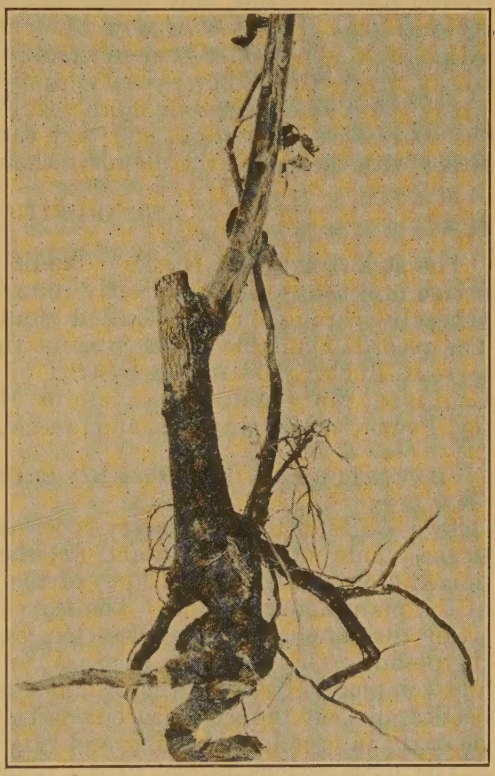

FIG. 2.—Roots of rose plant devoid of rootlets and severely injured by larvæ of the strawberry rootworm

Judging from the report made by H. F. Deitz, the Indiana infestation obviously was not so severe as the one at Alexandria. It was learned from the florist, however, that serious injury had occurred during May, the injuries being confined to Killarney rose plants growing in a solid bed in one of the five open-range houses infested. The condition there was similar to that existing at Alexandria, since the plants had been forced for about three weeks and had put forth an abundance of young, tender shoots. In the same locality Dietz noted this insect feeding on the foliage of out-of-door roses "growing next to a large strawberry bed, the leaves of which were badly riddled by the beetles."

Early in November, 1919, specimens of the strawberry rootworm were collected in the rose houses of the United States Botanical Garden at Washington, D. C., where they were doing serious injury.

During the winter of 1919–20 Primm and Trimble, of the Pennsylvania Bureau of Plant Industry, found infestations in 15 different establishments in the vicinity of Philadelphia. According to two florists in this locality, the beetles, known to them as "chocolate bugs," had been encountered in their houses for 12 and 18 years, respectively.

A careful survey by means of a circular letter sent to all the State entomologists and the subsequent publicity accorded this insect and its injury in florists' trade journals (*1*, *17*, *19*, and *24*) have brought to attention infestations in the States of Michigan, Missouri, Louisiana, Rhode Island, and Massachusetts. These reports emphasize the fact that the insect is now of prime importance in practically all of the commercial rose districts of the United States east of the Rocky Mountains. The severity of injury found in houses or beds where the plants were 3 or more years old indicated that they were the sources of infestation, and that the insect had been brought in either with the soil or the plants in those sections.

DISTRIBUTION

The strawberry leaf beetle, or adult of the rootworm, which is a native insect, has been frequently recorded as occurring out of doors generally throughout the United States and Canada (*14*, *p. 25*). The records available at the present time show that it is injurious to roses under glass in the District of Columbia, Illinois, Indiana, Louisiana, Maryland, Massachusetts, Michigan, Missouri, New Jersey, Pennsylvania, Rhode Island, and Virginia.

NATURE OF INJURY AND ECONOMIC IMPORTANCE

Two stages of the strawberry rootworm are involved in the injury to the plants, (1) the adult and (2) the larva. The casual observer immediately notices the ravages of the beetles on almost every part of the plant above ground. The leaves become perforated so extensively that one easily imagines charges of small shot being fired at the plants. This shot-hole appearance (fig. 1) is very characteristic and completely destroys the ornamental value of the foliage. The beetles also eat the green succulent bark of the forced plants, particularly in crotches, scarring and often girdling the stems.

The most serious injury to the plants occurs when the tops are "cut back," because little foliage remains for the beetle to feed upon. At this time the beetles severely scar the stems and eat into the "eyes," as the developing buds are termed by the florists. The importance of this particular type of injury is very evident when it is considered that the future crop of flowers depends on these buds, which require from six to eight weeks to develop, and that any setback naturally results in a decreased production and financial return. The succulent nature of this growth, as compared with the woody stems, causes the beetles to center their attention upon it, and in a single night they may eat the heart out of almost every eye. In one infestation observed in March, after the buds of Ophelia plants had been destroyed during September and October of the previous year, the first growth produced from these nodes was only

from 3 to 5 inches long. During this period no marketable blooms were obtained from these plants.

The beetles seldom attack the flowers, but when present in large numbers sometimes feed on the sepals, probably because they contain chlorophyll. In severe infestations the blooms of Columbia and Ophelia roses occasionally suffer injury, but the double white Killarney is rarely attacked.

Although the damage to the foliage occasioned by the beetles is more conspicuous, the roots are severely injured by the feeding of the larvæ, which not only devour the young feeder roots but also interfere with the normal functioning of the root system by girdling and gnawing into the older roots. (Fig. 2.) After two or three successive seasons of this feeding the plants become considerably weakened and the foliage assumes a "sickly" appearance, due to the cumulative effect of this injury. In some infested greenhouses the resulting mortality of plants in some beds ranged as high as 75 per cent, as indicated in Table 1, in which are recorded observations taken in 1920 by Primm and Chambers.

TABLE 1.—*Mortality due to larval injury by the strawberry rootworm in 17 ground beds, each containing 800 rose plants*

Bed No.	Number of dead plants	Mortality	Bed No.	Number of dead plants	Mortality
		Per cent			*Per cent*
1	333	41.6	11	25	3.1
2	279	34.9	12	5	0.6
3	333	41.6	13	22	2.8
4	145	18.1	14	67	8.4
5	425	53.1	15	27	3.4
6	276	34.5	16	312	39.0
7	209	26.1	17	600	75.0
8	280	35.0			
9 [1]	42	5.3	Total and average	3,398	25.0
10 [1]	18	2.3			

[1] Plants not cut back the previous season.

In one badly infested bed containing 800 plants 6 larvæ, on an average, were found among the roots of each plant, and in one case a maximum of 23 larvæ and pupæ were collected. When it is considered that these plants had been in the bed for five years and there subjected to larval attack for at least three years, it is not surprising that the foliage was yellow and that no flowers of any value were being produced.

Wounds in the roots are favorable points for the entrance of pathological organisms, and the resulting weakened condition of the plants renders them more susceptible to plant diseases.

The enormous number of beetles actually present in a heavily infested greenhouse may be readily appreciated from the following data: Since other control measures appeared inadequate, one establishment hired schoolboys for several weeks to hand-pick the adults, paying them at the rate of 25 cents per 100 beetles. The pay roll for these boys showed that as many as 60,000 were collected in one week at a cost of $150 (*32, p. 285*). Although several hundred thousand beetles were removed in this way, no diminution in their numbers was apparent. At another place many beetles were shaken

from the plants onto paddles covered with sticky fly paper, and where they were very numerous enough were collected along a 150-foot walk to cover a sheet of the paper; nevertheless, the plants continued to suffer from the ravages of those which escaped collection.

According to estimates of florists in Bucks and Montgomery Counties, Pa., damage to the extent of $70,000 was done to their greenhouse rose plants in 1920. The records of one grower show his gross income from one rose house to have been 74 cents per plant from July 1, 1919, to February 1, 1920, as compared with an income of $1.17 for the same period the preceding year. The decrease of 43 cents per plant was attributed almost entirely to the ravages of the beetles.

Another florist, whose gross annual return from 40,000 rose plants was from $70,000 to $80,000, estimated that his loss during 1921 was $9,000. He was unable to cut any salable flowers from June 25 until late in September, and his production suffered to some extent during the rest of the year. His loss may be analyzed as follows:

Cut flowers:		
Expected return during period when shipping was stopped	$4,320	
Actual return		$0
Loss		4,320
Estimated loss because of reduction of production		2,000
Insecticides:		
Tobacco dust, 50 tons at $35 per ton	1,750	
Fertilizer value at $10 per ton	500	
Insecticidal expense		1,250
Wood ashes, 25 tons at $30 per ton	750	
Fertilizer value at $10	250	
Insecticidal expense		500
Arsenicals and miscellaneous proprietary compounds and equipment	400	
Labor in application of insecticides, etc., 2,000 (estimated) man hours at 30 cents	600	
		1,000
Total		9,070

Losses and expenses such as are illustrated above will quickly absorb all the profits of a grower, because of the competition with other florists whose establishments are not suffering from the ravages of this insect.

LIFE HISTORY AND HABITS

ADULT STAGE

The original description of the variety *quadrinotata* as given by Say (*26, p. 446*) is as follows:

> Colaspis 4-notata: Black; head rufous; elytra testaceous, with two black spots. Inhabits the United States. Body black, punctured; head obscure rufous; antennae paler at base; thorax black; immaculate; punctures sparse, not profound; scutel pale reddish-brown; elytra pale testaceous, with striae of punctures which become obsolete before the tip; a black, oblique spot near the base of each and a larger obliquely quadrate one on the middle, exterior edge black; feet pale; thighs with a minute angle beneath. Length about three-twentieths of an inch.

It is evident that the name was given because of the four black spots on the elytra. The principal distinguishing color features are the black thorax, the brown elytra bearing the four black spots, and the absence of black markings along the suture.

Although Dejean (*8, p. 412*) used the name *gilvipes* for a species of Metachroma in his catalogue of Coleoptera, its use is held invalid because of the absence of description or reference to any type; and since Crotch (*7, p. 39*) was the first to use distinguishing characteristics for this variety, the authorship of the name is credited to him. Crotch lists *gilvipes* as a variety of *Paria sexnotata* with the very brief description: "Entirely black, legs pale." The name is evidently derived from gilvus (yellow) and pes (foot) and refers to the pale yellowish legs.

Horn (*16, p. 208*) indicates that the head of *gilvipes* is black, but Blatchley (*2, p. 1139*) shows that it may be reddish, and also that the antennæ as well as the legs are pale. The writer has found that the head is reddish in all specimens of *gilvipes* observed, and also that the black of the elytra grades into a pale Van Dyke brown color near the tips.

All individuals of both varieties of the beetles found in the greenhouses have been of a uniform size, and no differences have been noted among specimens from the several widely separated infestations. The length ranges from 2.8 to 3.6 millimeters and the width from 1.6 to 2 millimeters. It is interesting to note, however, that specimens of the same varieties which had been collected out of doors were much larger, being 4.5 millimeters long and 2.3 millimeters wide.

FIG. 3.—The strawberry rootworm. Adult of the variety *quadrinotata*

When the beetles are first transformed from the pupæ they are very light in shade, but upon exposure to the air soon acquire the normal coloration and markings. The ventral surface of the body becomes black in both varieties.

The four-spotted variety, *quadrinotata* (fig. 3), has been more prevalent in greenhouses, and was encountered in every infestation observed; but the closely related *gilvipes*, with its black body and pale legs, has also been found simultaneously in several establishments in considerable numbers. Practically all of the observations on the adult were made on individuals of the variety *quadrinotata.*

CAGE FOR OBSERVATIONS ON ADULT STAGE

The type of cage used for most of the observations on the adult stage was a glass vial or test tube 1 inch in diameter and from 3 to 5

inches long closed with a cork. A piece of cloth placed under the cork before the latter was pushed down into the vial was found advantageous in preventing the beetles from laying eggs in the crevices of the cork and also in absorbing any moisture of condensation which might otherwise drip down the sides of the vial.

LONGEVITY

It was not possible to reduce to an arithmetical basis the longevity of the adults in the greenhouses, because the time from emergence to date of collection could not be determined. Beetles under observation lived as long as 234 days after date of collection.

It seems probable that under favorable greenhouse conditions the adults which emerge during the spring and summer months may live from 75 to 100 days, whereas those which emerge later in the season and pass the winter in the semidormant condition may remain alive for a longer period. Table 2 indicates an average longevity of 52 days for reared specimens in confinement, although one individual lived 364 days.

TABLE 2.—*Longevity of 45 strawberry rootworm beetles reared from pupæ in 1921 and 1922*

OBSERVATIONS AT WASHINGTON, D. C.

Number of beetles	Date of—		Length of life	Remarks
	Emergence	Death		
	1921	1921	*Days*	
3	June 27	June 29	2	No feeding.
6	27	July 1	4	Do.
2	27	2	5	Do.
3	27	9	12	
1	27	21	24	
1	27	27	30	
1	27	Aug. 17	51	
6	27	Oct. 19	114	4 eggs from 1 beetle.
1	27	Dec. 4	160	58 eggs.
		1922		
1	27	June 26	364	51 eggs.

OBSERVATIONS AT DOYLESTOWN, PA.

	1921	1921		
1	June 1[1]	June 16	15	
1	1[1]	Sept. 6	97	40 eggs.
1	4[1]	July 7	33	No data on egg deposition.
1	July 2	Oct. 3	93	Do.
1	Aug. 3	Sept. 22	50	Do.
1	3	Aug. 30	27	Do.
1	4	Oct. 17	74	Do.
	1922	1922		
1	June 27	June 28	1	
2	27	July 25	28	
1	30	Aug. 14	45	
1	July 7	14	38	
1	17	Nov. 1	107	
1	27	Aug. 21	25	
1	27	Sept. 21	56	
1	29	Aug. 3	5	
1	29	Oct. 26	89	
1	Aug. 1	Aug. 22	21	
1	7	Nov. 1	86	
1	16	Sept. 21	36	
Total, 45			2,343	

	Days
Average length of life	52
Maximum length of life	364
Minimum length of life	1

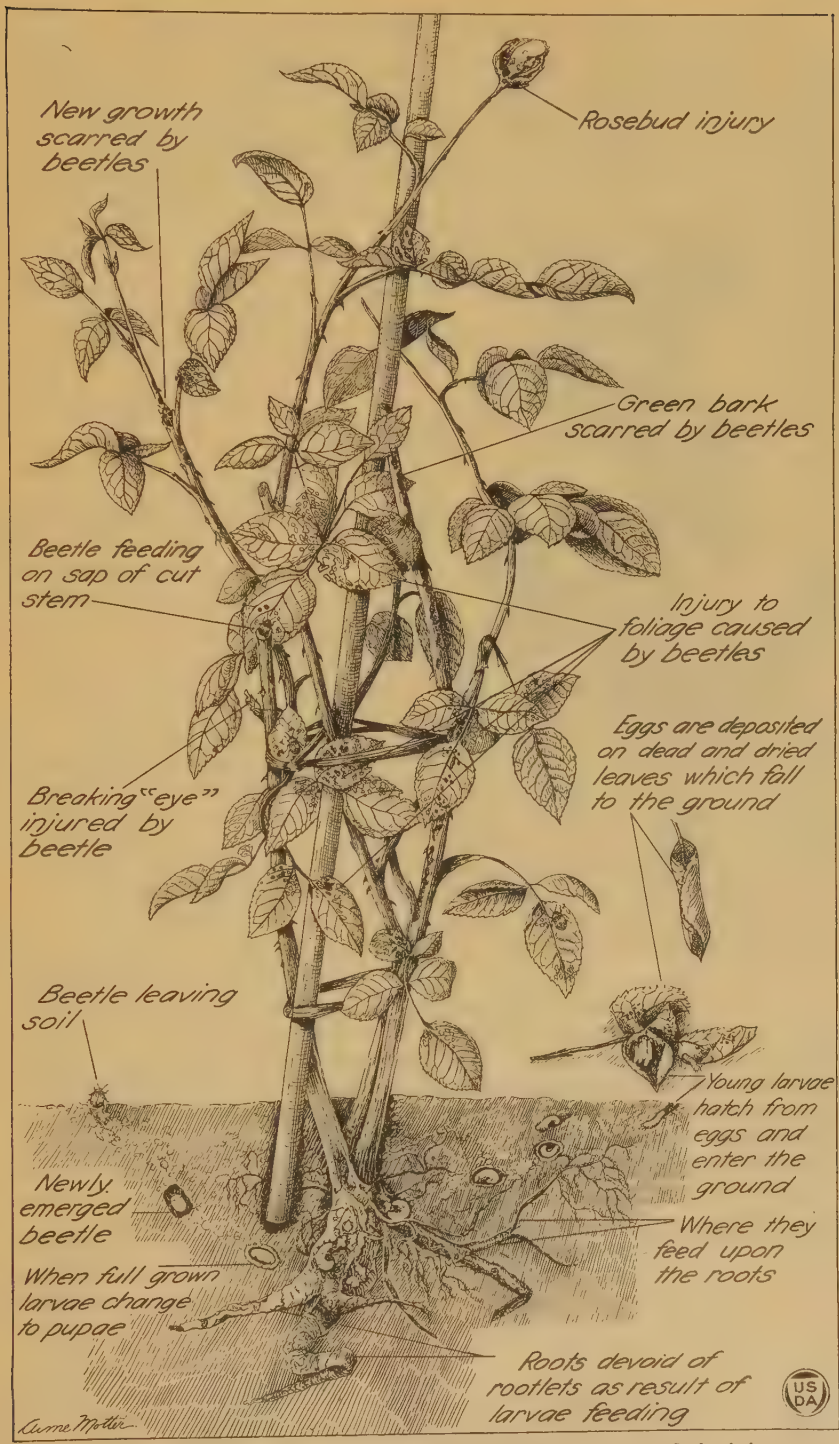
New growth scarred by beetles
Rosebud injury
Green bark scarred by beetles
Beetle feeding on sap of cut stem
Injury to foliage caused by beetles
Eggs are deposited on dead and dried leaves which fall to the ground
Breaking "eye" injured by beetle
Beetle leaving soil
Young larvae hatch from eggs and enter the ground
Newly emerged beetle
Where they feed upon the roots
When full grown larvae change to pupae
Roots devoid of rootlets as result of larvae feeding
USDA

FIG. 4.—The stages in the life history of the strawberry rootworm and the injury caused by the larvæ and adults

HABITAT

On bright days the beetles hide in the dried leaves on the bushes, between adjacent green leaves, in the crotches, or in any place where they are away from the light, and come out to feed in the late afternoon (Fig. 4). Usually wherever fresh feeding is evident on the foliage an examination of the nearest dry leaf will reveal their presence. They may often be found in depressions one-half inch deep in the ends of cut stems where the pith has dried out.

FIG. 5.—The strawberry rootworm: Characteristic feeding of the adults on terminal growth and flower bud

Syringing causes many of the beetles on the plants to drop to the ground, where they may remain for some time. Watering as well as syringing wets the soil to such an extent that the adults dislike it and run up the stems, stakes, and plants, or rest on the wires, apparently to dry themselves. While the beetles were thus exposed, more than a thousand were collected within an hour by the workmen in a house containing 30,000 plants. Two or three hours after syringing the beetles again hide among the foliage of the plants or elsewhere.

FEEDING HABITS

The leaves (fig. 1) furnish most of the adults' food, although the bark of the stems, the buds (fig. 5), and the flowers do not escape attack. The beetles are attracted particularly by the sap on the ends of new-cut stems, and in the evening as many as 10 have been found feeding there. Under these conditions hand picking may be successfully practiced. In the absence of foliage the beetles cause very serious injury by feeding on the breaking buds. The extent of this feeding is shown in Table 3, which records data gathered in three separate greenhouses.

TABLE 3.—*Injury to "wood buds" of rose plants by strawberry rootworm beetles in three different establishments*

Establishment	Total number of—			Percentage of injured buds
	Plants examined	Breaking buds	Injured buds	
A	50	2,313	878	38
B	30	1,013	637	62
C	53	590	349	59

Sixty adults given fresh leaves twice daily ate 372 of the characteristic "shot-hole" punctures (fig. 1) the first day, 386 the second day, and 325 the third day, averaging 6.2, 6.4, and 5.4 feeding punctures per adult on the respective days, or an average over the whole period of 6 such areas for each beetle per day. It was observed to require about six minutes for a beetle to eat one hole in a leaf.

Further experiments, as indicated in Table 4, gave an average of between 4 and 5 feeding punctures per day for each individual.

TABLE 4.—*Amount of feeding by strawberry rootworm beetles during September, 1921*

Period (first and last dates, inclusive)	Number of—		Feeding punctures—			Remarks
	Days	Adults	Total number	Average		
				Per day	Per adult per day	
Aug. 31 to Sept. 2	3	47	645	215	4.57	
Sept. 3 to Sept. 6	4	46	1,103	276	6.00	1 dead.
Sept. 7 to Sept. 10	4	45	947	237	5.27	Do.
Sept. 11 to Sept. 14	4	43	704	176	4.09	2 dead.
Sept. 15 to Sept. 17	3	43	528	176	4.09	
Sept. 18 to Sept. 22	5	43	463	93	2.16	
Sept. 23 to Sept. 27	5	43	446	89	2.07	

PROTECTIVE HABITS

As is characteristic of certain other insects, this beetle at the least disturbance folds its legs and antennæ under its body, rolls from the leaf, and remains motionless on the ground for several minutes. This so-called "possum" or death-feigning habit is also protective and is more common than the "squirrel" habit, by which they escape being seen. If approached during the day, any beetles visible on the plants immediately conceal themselves behind leaves, stems, stakes, or elsewhere. When one walks through a heavily infested house at night he can hear the beetles dropping from the bushes about 10 feet ahead, and when the beetles are present in large numbers the sound is similar to the patter of a gentle rain. The coloration of the beetles blends with that of the earth or mulch, and it is difficult to locate them on the soil unless they move.

The beetles do not necessarily reach the ground when they drop from the plants, for they are apt to fly at any time during their fall. In fact, when within a foot of the soil they have been observed to spread their wings and fly to near-by leaves. The range of continuous flight appears to be limited, as 30 feet was the maximum distance observed. In one house, where the plant tops had been cut back and removed during the day, many beetles were seen on the walls and roof, where they were apparently trying to escape from the house by making short flights of from 5 to 10 feet at a maximum altitude of 10 feet.

FERTILITY AND PARTHENOGENESIS

Mating was not observed and males have never been seen among the numbers of individuals collected under glass. Peterson (*23*, *p.*

473) says: "No male adults have been seen at any time in our three years of observation with this species." Males are known to occur out of doors, and these observations indicate possible thelyotoky in the greenhouse forms. Whether or not they are fertilized, it is an outstanding fact that practically all the eggs in the masses observed in greenhouses have hatched.

Although 25 adults which emerged on the same day were removed from the rearing cage and confined singly, so that the only possible access to males was before they were isolated, three of them deposited eggs. In another case eggs were obtained from two reared adults which were segregated immediately after emergence. In this connection Peterson (*23*, *p. 473*) observes that the ovaries of newly emerged adults are in an immature condition and do not develop to any extent until the adult has consumed some food. At first the

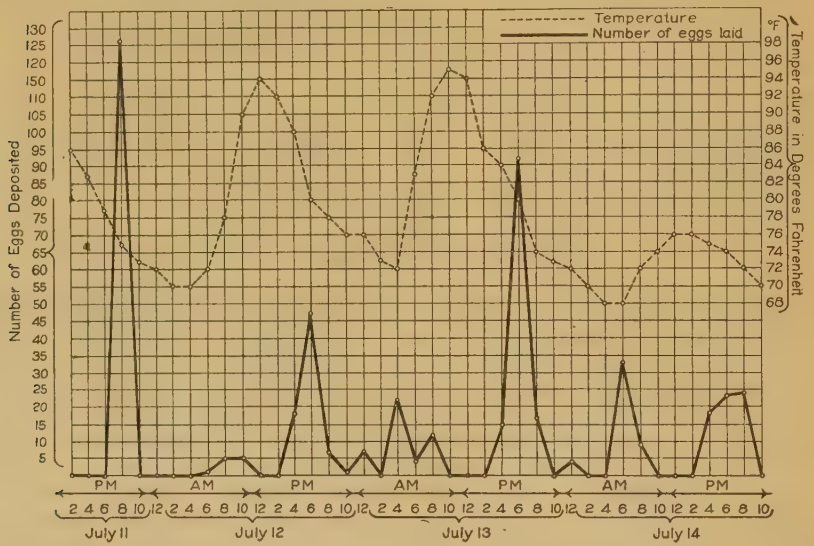

FIG. 6.—Egg deposition by strawberry rootworm adults. Records every two hours from July 11 to 14, inclusive, Doylestown, Pa., 1922

abdomen is very soft and does not become full and hardened until seven days after emergence, so that, although possible, it is doubtful whether mating takes place while the female is in this undeveloped state. Furthermore, as is shown in Table 7, no eggs were laid by reared individuals until 19 days after emergence, or 18 days after they were isolated. From the foregoing circumstantial evidence it would appear that parthenogenesis is a possible feature of the biology of this insect under greenhouse conditions.

OVIPOSITION

Oviposition may take place, at least to a limited extent, throughout the year, since the eggs have been obtained from caged beetles in each month. In the greenhouse, however, most of the eggs were laid in the spring and early summer months. The earliest records of the finding of eggs in the rose houses are March 9, 1920, March 1, 1921, and March 14, 1922, and after these dates eggs could be

found almost continuously until August, at which time they were less numerous, and none have been collected in greenhouses after August 31 in any year. These records are very similar to observations on caged beetles, as indicated in Table 5.

TABLE 5.—*Total number of eggs laid by caged strawberry rootworm beetles, 1922*

Date of deposition	Number of—			Date of deposition	Number of—		
	Eggs	Adults	Eggs per adult		Eggs	Adults	Eggs per adult
Mar. 27	12	59	0.20	June 21	20	124	0.16
29	17	90	.19	22	57	123	.46
Apr. 3	67	107	.63	23	105	121	.87
6	28	115	.24	26	221	117	1.89
8	34	115	.30	28	27	116	.23
10	149	115	1.30	29	101	109	.93
13	168	111	1.51	30	13	109	.12
15	68	111	.61	July 1	434	102	4.25
17	33	76	.43	3	251	98	2.56
19	21	52	.40	5	243	95	2.56
21	22	52	.42	8	352	147	2.39
24	92	50	1.84	10	206	131	1.57
26	39	50	.78	12	53	127	.42
28	35	50	.70	14	532	127	4.19
May 3	147	50	2.94	15	56	118	.47
6	76	48	1.58	18	322	117	2.75
8	142	47	3.02	22	621	114	5.45
11	153	46	3.33	25	636	114	5.58
15	112	44	2.55	28	561	134	4.19
17	62	44	1.41	31	622	131	4.75
20	76	43	1.77	Aug. 1	378	131	2.89
22	160	42	3.81	2	176	129	1.36
24	148	64	2.31	3	101	128	.79
26	122	66	1.85	5	296	128	2.31
29	221	65	3.40	7	583	128	4.55
31	181	59	3.07	9	182	127	1.43
June 3	176	54	3.26	11	265	123	2.15
5	246	56	4.39	14	159	120	1.33
7	303	55	5.51	17	125	118	1.06
9	178	65	2.74	21	124	114	1.09
13	468	64	7.31	29	116	93	1.25
14	12	64	.19	Sept. 21	34	46	.74
17	157	62	2.53	Total	12,002	6,016	2.00
19	105	66	1.59				

Figure 6 shows the results of observations on 60 caged adults made every 2 hours over a period of 80 hours, during which 490 eggs were laid, and is based on data contained in Table 6. According to these records, the time of day most favored by the female for egg deposition is the late afternoon, and next to that the early morning hours.

TABLE 6.—*Egg deposition by adults of the strawberry rootworm; observations upon which graph of Figure 6 is based*

Date of oviposition	Number of eggs laid—												Total number of eggs
	p. m.	a. m.					m.	p. m.					
	12	2	4	6	8	10	12	2	4	6	8	10	
July 11	[1]							[2]	[1]		126	0	126
12	0	0	0	1	5	5	0	0	18	47	7	1	84
13	7	0	22	4	12	0	0	0	15	92	17	0	169
14	4	0	0	33	9	0	0	0	18	23	24	0	111

[1] No data.

[2] Observation started.

Observations on the process of egg deposition by two beetles confined in one vial at 2 p. m. were as follows: While seeking a place to deposit eggs the beetles, moving their heads with a rocking motion, touched or "measured" the surfaces of crevices or depressions in the cork alternately with the tip of each antenna, and then tried them out with the tip of the ovipositor slightly extended, moving rapidly from one to another. These two individuals were then placed in separate vials with a small piece of dry and crumpled leaflet. One adult ran nervously about for a time, while the other on finding the leaf settled immediately and began to oviposit.

Considerable time was spent in preparing a resting place for the eggs. After the long, flexible ovipositor had been inserted, a thin

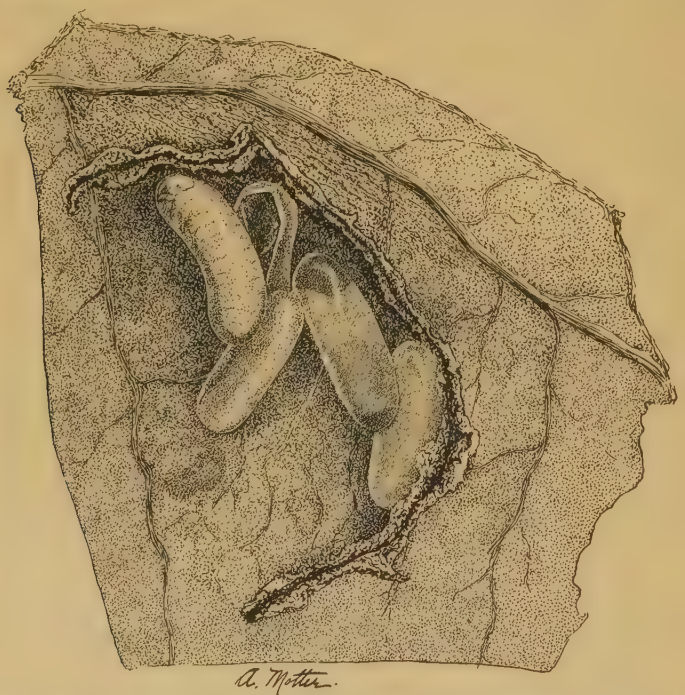

FIG. 7.—Egg mass of the strawberry rootworm on portion of dead leaf, showing development and characteristic wall which surrounds each egg mass. Enlarged

transparent fluid was secreted at its tip in tiny droplets, and then spread or brushed over both surfaces of the depression with two hairy palpuslike projections of the ovipositor. Twelve minutes were spent preparing the surface and four minutes in forming that portion of the wall against which the eggs were to be placed. A tiny droplet of the thin fluid preceded and another followed each egg as it was ejected from the ovipositor, and an interval of about two minutes elapsed between the ejection of each egg. The egg was placed with the help of the palpuslike brush, which at the same time spread some of the fluid over the egg and in the spaces around it. When all the eggs had been placed the beetle constructed a wall (fig. 7) to surround the egg mass by secreting a second fluid, which

was thicker and contained small lumps, and which evidently served as a means of keeping the two surfaces between which the eggs were laid from pressing together and crushing them.

The material forming this wall was translucent when secreted, but turned dark and finally black about three hours later. While the fluid was being spread the beetle rubbed its hind and middle tarsi together, apparently for the purpose of removing the sticky fluid which adhered to them. Although the legs were usually kept well braced, the beetle occasionally supported the turgid ovipositor with one of its hind legs. At times the ovipositor would be retracted, only to be immediately extended again. The beetle turned slightly several times to allow the ovipositor to reach a different spot, but all reaching was done by the ovipositor alone and there was no motion of the body which assisted in placing it between the leaf surfaces. In another instance an adult was observed to begin oviposition at 7.15 p. m. and finish at 8.05 p. m., a period of 50 minutes, during which four eggs were deposited.

A few records of duration of the preoviposition and postoviposition periods of strawberry rootworm beetles and of the number of eggs deposited are contained in Table 7.

TABLE 7.—*Duration of preoviposition and postoviposition periods of the strawberry rootworm beetle, 1921*

Date of—		Preoviposition period	Number of eggs deposited	Date of—		Postoviposition period
Emergence	First egg			Last egg	Death	
		Days				*Days*
June 1	June 20	19	40	July 31	Sept. 6	37
27	July 27	30	58	Aug. 12	Dec. 4	114
27	27	30	51	12	June 26[1]	318
27	Aug. 8	42	4	8	Oct. 19	72

[1] 1922.

The maximum number of eggs laid was 216, and these eggs were deposited by a beetle in 22 different egg masses in a period of three months after it was collected in the greenhouse. Several instances have been noted in which collected individuals have laid more than 100 eggs. Observations on caged beetles under greenhouse conditions indicate an average of 135 eggs as the probable normal capacity of a female.

EGG STAGE

The egg (fig. 7.) of the strawberry rootworm beetle is pale lemon yellow when deposited and becomes slightly orange as it develops. It is elongate oval and very slightly arched. The cephalic end is somewhat blunter than the caudal end. The length is from 0.93 to 0.98 millimeters and the width from 0.25 to 0.27 millimeters.

In greenhouses the eggs are usually deposited on old dead leaves (fig. 4) more or less folded or curled. Although eggs have been found in such leaves on the soil, it is more than probable that they are laid before the leaf falls to the ground, since, where an infestation

is heavy, eggs may be found in 50 per cent of the dead leaves still clinging to the plants. In one instance two egg masses were noticed between the petals of half-opened buds, and in two other cases egg masses were discovered inside of flattened straw in the manure mulch. Captive beetles, in glass vials closed with cork, have deposited eggs on green leaves, in crevices of the cork, and in practically any place where there were two contiguous surfaces; eggs have even been laid between the cork and the glass or on the glass when a leaf rests against it. These beetles, however, have shown a preference for dry leaves when such have been kept in the vials.

Observations on egg deposition in cages and in the greenhouse during three successive years gave a maximum of 23 eggs per mass. The data presented in Table 8 indicate that this number is exceptional, and that more of the egg masses contain 2 to 5 than 6 to 10 eggs. Although these figures are based on deposition by caged beetles, egg masses collected in the greenhouse did not vary from these results.

TABLE 8.—*Number of eggs per mass in egg masses of the strawberry rootworm beetle*

Number of—		Number of—		Number of—	
Eggs per mass	Egg masses	Eggs per mass	Egg masses	Eggs per mass	Egg masses
1	81	8	50	15	3
2	167	9	24	16	2
3	258	10	24	17	3
4	212	11	11	18	5
5	141	12	11	19	1
6	123	13	4	20	1
7	76	14	8	23	1

DEVELOPMENT

The first signs of development are noted as the ends of the egg become translucent 36 to 60 hours after deposition. Segmentation becomes indistinctly visible about the seventh day or later. The tips of the mandibles begin to show as they become chitinized about the eighth day. At this time the embryonic larva is nearly developed and within 24 hours the larva breaks the shell.

The period of incubation was usually from 7 to 18 days in length, although a few individuals hatched in 4 days and a few others not until 27 days, the length of time depending on seasonal conditions. The reasons why the records for 1921 varied from those of 1920 are unknown, and in order to check these results the incubation periods of large numbers of eggs were observed during 1922. These data are given in Tables 9 and 10.

TABLE 9.—*Variation in length of the period of incubation of eggs of the strawberry rootworm beetle during 1920 and 1922, by months*

1920

Period of incubation	Number of eggs hatched during—					Total number of eggs hatched
	March and April	May	June	July	August	
Days						
7	0	0	0	2	0	2
8	0	0	2	6	0	8
9	0	0	4	1	0	5
10	0	1	1	0	0	2
11	0	3	0	0	0	3
12	2	5	1	0	0	8
13	6	12	0	0	0	18
14	1	2	0	0	0	3
15	0	2	0	0	0	2
Average in days	12.89	12.68	9.25	7.89	0	11.32

1922

4	0	0	0	6	0	6
5	0	0	0	1	0	1
6	1	0	0	7	0	8
7	1	0	158	707	99	965
8	0	0	174	58	245	477
9	0	14	389	577	166	1,146
10	2	119	393	244	137	895
11	1	52	160	327	56	596
12	6	208	115	45	17	391
13	10	34	4	49	6	103
14	8	68	64	27	0	167
15	9	74	0	0	0	83
16	40	62	0	0	0	102
17	25	54	0	0	0	79
18	35	12	0	0	0	47
19	0	13	0	0	0	13
20	2	2	0	0	0	4
21	0	1	0	0	0	1
22	0	0	0	0	0	0
23	1	0	0	0	0	1
Average in days	15.96	13.07	9.62	8.92	8.84	9.89

TABLE 10.—*Time of deposition and hatching and period of incubation of eggs of the strawberry rootworm beetle in 1921*

Date of deposition	Number of eggs—		Date of hatching	Incubation period	Date of deposition	Number of eggs—		Date of hatching	Incubation period
	Deposited	Hatched				Deposited	Hatched		
				Days					*Days*
Mar. 22	52	15	Apr. 8	17	Apr. 6	33	1	Apr. 26	20
		2	12	21	6	19	1	26	20
30	64	4	26	27	19	33	2	May 9	20
31	35	8	18	18	21	26	2	9	18
		2	21	21	21	36	4	9	18
Apr. 2	11	3	19	17					
4	65	7	26	22					
		2	27	23					

HATCHING

Observations on the hatching of two larvæ, A and B, were as follows: When first observed A was yellowish in color with a transparent head and dark brown mandibles. It had already broken or chewed one end of the shell and had freed its entire abdomen by

moving backward through the opening, after which it crawled inside and began to chew and swallow small portions of the broken shell, consuming about one-fourth of it. About an hour later it turned around and chewed at the other end. After 70 minutes the head was still rather transparent but had become brownish.

When observed at 10.15 a. m., specimen B was curled up in the shell, flexed dorsally at about the division of the thorax and abdomen, and seemed to be pushing upward on the shell. No ruptures in the shell were visible at this time. The larva then straightened out and twisted itself around so that its mouth reached the place where the back had been pressing against the shell, where it had chewed an opening by 10.55 a. m. At 11.45 a. m. it again returned to its first position and was pressing with its back against the break in the shell, enlarging the opening. A wavelike motion, extending from the tip of the abdomen forward toward the head, accompanied the pushing and helped break open the shell. Following this the little larva straightened its head and thorax, keeping the abdomen in the same position as when pushing. The opening was apparently not

FIG. 8.—Strawberry rootworm. Lateral view of larva, enlarged

large enough for the head to get out. At noon the larva, by curling the end of its abdomen slightly forward, shoved itself backward until its head could be thrust out through the opening made. At this time there was no differentiation in the color of the head and the body.

LARVA STAGE[5]

The full-grown larvæ or grubs (fig. 8) are from 4 to 5 millimeters long and 1.1 to 1.4 millimeters wide. They are entirely white except for the head and the dorsal surface of the prothorax, which are pale yellowish brown. The prothoracic segment, which is firmer in structure and bears only one fold, is leathery and smooth above and a little longer than the other segments. The remaining segments are each marked with three transverse dorsal folds, which terminate on the sides in large, low elevations, pointed ovate in form (the pointed ends being upward), one to each segment of the body excepting the head, prothorax, and anal segment.

There are nine spiracles on each side of the body, the first larger than the others and located between the prothoracic and mesothoracic segments, whereas the others are placed on the abdominal segments, except the last. They are at the lower ends of the ovate elevations mentioned above. Below the row of spiracles there is a row of prominent tubercles, one to each segment, forming a longitudinal groove between this row and the elevations above the spiracles. On each ovate elevation there is just above the spiracle a small mound from the center of which arises a seta. A similar seta arises from each tubercle of the first row. Below this row of tubercles is a longitudinal fold on each segment,

[5] The description of the larva is based on that given by Forbes (*18, pp. 151–152*), with some additions and modifications.

which forms the upper side of a longitudinal groove, the lower edge of which is made up of the coxæ of the legs on the thoracic segments and a row of only slightly prominent tubercles on the abdominal segments, one on each. Each tubercle in this second row bears a bunch of from two to four setæ. A transverse ventral ridge is present on each abdominal segment and bears two groups of short spines on each side of the ventrimeson. These form two longitudinal rows along the abdomen. The medial groups are each composed of from 8 to 10 spines, except those on the last segment, which only have 4 or 5 spines, while the outer groups have from 4 to 6 spines. All the spines on the abdominal ventral ridges arise at a sharp, acute angle from the body and point backward.

The head is smooth, somewhat flattened in front, and bears a few setæ. The clypeus is transverse, trapezoidal, narrowing forward, and the labrum is rounded in front. The minute antennæ are four-jointed, the outer angle of the third joint being continued in a cylindrical process which reaches to the end of the triangular fourth joint. The maxillæ are moderately developed. The cardinal and basal pieces are not well distinguished, the maxillary lobe is armed with stout spines within, and the palpi are prominent and four-jointed The labium is thick and semicircular, with little appearance of a palpigerous tubercle. The labial palpi are slender, cylindrical, and unarticulated. The bifid mandibles are dark brown with black tips, and therefore stand out in marked contrast to the light-colored head and body.

The legs are about as long as their corresponding segments and are white, with the exception of the simple claws, which are dark brown at the tips. There are a few setæ on the legs, becoming short and spinelike toward the claws.

EARLY ACTIVITIES AND LOCATION IN THE SOIL

That the newly emerged grubs are very active and have considerable vitality was demonstrated when five larvæ were kept in a small gelatine capsule with only the dried leaf bearing the empty eggshells from which they hatched. They remained alive from three to five days.

The leaf (fig. 4) carrying the egg mass may drop or be washed to the ground by the force of the syringing water before the larvæ hatch, so that they may crawl off directly on the soil; but if the leaf is still stuck to the twigs or stakes the larvæ do not hesitate to drop off. Newly hatched larvæ have been placed on a piece of paper and their course of travel traced. Their tortuous trail was in every case made up of a series of loops, always to the right if the little larva started that way, or to the left if the first turn was to the left. One larva traveled a distance of approximately 36 inches in 63 minutes, at the end of which it was 4¼ inches in a straight line from the starting point, having crossed its path 15 times, always turning to the right. These actions probably explain why the larvæ always bore their way into the soil with a spiral motion.

Presumably the larvæ enter the ground (fig. 4) as soon as they abandon the leaf on which they hatched. Larvæ placed on the soil of beds immediately after hatching entered the ground not more than 2 inches from where they were first placed. Others put on the soil of potted plants would bore into the first crevices or openings which they encountered. Only in a very few instances were these newly hatched larvæ observed to remain on the soil surface longer than 15 minutes. Some larvæ which were dropped on soil from a height of 18 inches immediately worked their way into the ground, and 75 per cent of them were found alive three days later.

The entire larval stage is spent in the soil (fig. 4), usually close to the ball of roots of the rose plants. Oftentimes larvæ have been

collected 8 to 10 inches from the main stem of a plant, and at a depth of 6 to 7 inches from the surface. Usually they are found at a depth of 2 to 3 inches, and as many as 19 specimens have been found among the roots of a single plant.

FEEDING HABITS

Although their first attention seems to be given to the smaller feeding rootlets, the larvæ also gnaw and penetrate the main roots. (Fig. 2.) They have been observed to girdle the crowns just below the soil surface, resulting in the loss at one establishment of over 100 "own-root" plants which had been set about three months previously. Older bushes can withstand more severe feeding before showing the effects. Plants in a decidedly poor condition had been growing in a bed for five years and showed many furrows in the main roots which had evidently been the source of larval nourishment. Only a few new growths were produced after "pinching" the shoots, and these were short and weak because the vitality of the plants was very low, and the foliage lacked its normal green color. These plants were used for experimental work on the soil stages and accurate counts were made of the number of larvæ and pupæ found in each. During the examination of 481 of these plants 2,991 larvæ and pupæ were found, or an average of 6.22 to a plant, the maximum being 23 specimens.

Examination made in August, 1921, of the roots and soil around 58 plants dug up at random in different sections of a greenhouse where 3,000 plants were being removed, showed that 130 larvæ and 150 pupæ were present, or an average of 4.8 specimens of the soil stages to each plant. If this condition prevailed throughout the house it would mean that there were 14,400 individuals in the soil at that time. Since egg laying is continuous throughout the spring and early summer months, the roots of these plants had probably been subjected for several months to attacks by successive large broods of larvæ.

A comparative lack of the fresh white feeding rootlets was conspicuously evident in the case of the infested plants mentioned above. Even though very few of the older plants die as a direct result of the larval attack, they become so weakened that many of them fail to withstand the rigorous treatment accorded the bushes when subjected to artificial dormant conditions. It is a cultural practice among the growers during the drying-off period to withhold water from the plants for a period of from two to four weeks or longer, after which the greater part of the growth is pruned off until only from 12 to 18 inches of the main stems are left. Moisture is again made available to the roots, and normal plants will immediately put forth new growth from the buds. Extensive injury to the root systems (fig. 2) prevents them from functioning normally and results in the loss of the more severely injured plants.

In less than three days 23 newly hatched larvæ confined in a vial with soil containing roseroots chopped in half-inch lengths have eaten the equivalent of 10 inches of roots which were approximately one-sixteenth to three thirty-seconds of an inch in diameter. In several instances where pupæ were kept in the same cage they were chewed by the larvæ. That the larvæ are able to burrow through the

bed from plant to plant is indicated by the fact that when confined in pill boxes or cages with soil they pulverized the earth very thoroughly.

MOLTING

Very little is known regarding the number of molts and the time of molting. One larva which was 4 days old was seen freeing itself from the old skin. This was probably the first molt, but nothing further was noted.

DURATION OF THE LARVAL STAGE

From an examination of Table 11 it will be seen that the duration of the larval period is from 33 to 74 days. Seasonal conditions, as well as moisture and temperature, undoubtedly affect the length of this stage. In cases where the date of pupation was not noted, the duration of the larval period was calculated by deducting 8 to 11 days, the time usually required for the pupal stage, from the number of days between hatching and the emergence of the adult.

TABLE 11.—*Duration of larval and pupal stages of the strawberry rootworm, 1920, 1921, and 1922*

[Observations taken at Doylestown, Pa., except those on June 11, 12, and 14, 1922, which were taken at Washington, D. C.]

Number of individuals	Date of—			Duration of stages			Remarks
	Hatching	Pupation	Emergence	Larva	Pupa	Larva and pupa	
	1920	1920	1920	*Days*	*Days*	*Days*	
1	Mar. 24	June 4	June 16	72	12	84	
2	24	6	18	74	12	86	
2	June 3 and 4	Aug. 1	Aug. 14	58 to 59	13	71 to 72	
4	3 and 4	1 to 5	16	58 to 63	11 to 15	73 to 74	
4	3 and 4	1 to 5	18	58 to 63	13 to 17	75 to 76	
	1921	1921	1921				
1	May 2		June 29			58	Pupation not observed.
4		July 1	July 12		11		Hatching not observed.
2		2	12		10		Do.
5		7	15		8		Do.
2		Aug. 4	Aug. 15		11		Do.
2		5	14		9		Do.
	1922	1922	1922				
1		June 5	June 15		10		Do.
3	Apr. 30 to May 6		27			52 to 58	Pupation not observed.
1	30 to May 6		30			55 to 61	Do.
2	May 11	July 5		55			Died before emergence.
2	26	19	July 27	54	8	62	
1	27	15		49			Do.
1	29	15		47			Do.
1	31		July 27			57	Pupation not observed.
3	June 3		29			56	Do.
1	7	July 27	Aug. 1	50	5	55	
1	7	27	7	50	11	61	
2	23	Aug. 16		54			Died before emergence.
1	11		July 25			44	Pupal stage estimated as 8 to 11 days.
2	12		25			43	Do.
5	14		25			41	Do.

	Days
Average length of larval stage (based on 23 specimens)	58
Maximum length of larval stage	74
Minimum length of larval stage	47
Minimum length of larval stage (estimated)	33
Average length of pupal stage (based on 33 specimens)	10.9
Maximum length of pupal stage	17
Minimum length of pupal stage	5

PUPA STAGE [6]

The pupæ (fig. 9) at first are whitish throughout. The eyes are dark and the mandibles become brown about the middle of the pupation period. When the pupa is about three-fourths mature the tips of the metathoracic wings become dark gray, following which the mesothoracic wings, which develop into the elytra of the adult, become somewhat brownish owing to the development of the chitin. When first formed, with the wings still folded close to the body, the pupa is from 3.8 to 4.3 millimeters long and 1.9 to 2.1 millimeters wide. As it develops the pupa becomes somewhat shorter and a little stouter, approaching the shape of the adult. The head of the pupa is bent down slightly and the legs folded against the under side of the body, the metathoracic pair being applied against the sides of the abdomen, while the femora of the prothoracic and mesothoracic pairs project at right angles, with the tibiæ folded up close to the femora. The wing pads are wrapped around the metathoracic legs. The antennæ are held close to the body and curve under the distal part of the femora of the two anterior pairs of legs. The front of the head bears a few long setæ with bulblike bases; three transverse rows of similar hairs are present on the dorsal side of the prothorax, and the scutellum bears one on each anterior corner with a pair on either side and slightly in front. There are six on the upper side of the metathorax and a row of eight on each abdominal segment. The last segment of the abdomen terminates in two simple spines which curve dorsally. The spines are dark in color and become quite dark when the pupa is almost mature. In front of these hooklike projections are two pairs of lateral setæ, one on the last and the other on the next to the last segment, which project backward. A strong, curved hook, similar to the anal hooks, arises from the posterior inferior angle of the tibiofemoral articulation of the metathoracic legs. These curve down and in toward the body and each bears a long bristle near the point. The anterior angles of this joint bear two long setæ with inflated bases, and similar setæ arise from the anterior angles and the middle of the inferior margin of the corresponding joints of the other two pairs of legs, which do not bear spines, however. The ventral surface of the pupa bears no setæ or spines. The abdomen is slightly curved ventrally.

FIG. 9.—Strawberry rootworm. Dorsal view of pupa. Enlarged

PUPATION, LOCATION OF PUPA, AND LENGTH OF PUPAL PERIOD

The full-grown larvæ hollow out small earthern cells and there change to pupæ. (Fig. 4.) Most of the pupæ collected have been found within 2 inches of the soil surface, and when the cells were broken into the disturbed pupæ would move their abdomens back and forth very vigorously with a motion which apparently served the purpose of keeping the cavity hollowed out. When sifted soil is dropped on a pupa resting in one-half of its cell, the particles are swept out of this cavity by three or four movements.

The duration of the pupal stage was from 5 to 17 days, as indicated in Table 11, but from 8 to 11 days appeared to be the usual time required for this stage.

[6] The description of the pupa is based on that given by Forbes (*18, pp. 152–153*), with some additions and modifications.

SEASONAL HISTORY

There are two generations a year of the strawberry rootworm when it spends its life in greenhouses. The curious feature of its habits under greenhouse conditions is the pseudohibernation which it undergoes. The beetles which emerge in late summer and early fall—August, September, and October—pass the greater part of the winter in hiding, either in the surface mulch or in the dried leaves on the plants. During this time they are not in a true dormant state, since they occasionally come from their hiding places, particularly on warm, clear days, and feed. It is possible that this habit can be accounted for as a vestige of the natural life of the insect out of doors, where it hibernates as an adult in a true dormant condition.

Since a minimum temperature of 60° F. at night and about 80° F. during the day is maintained in rose houses during the winter, temperature conditions apparently do not account for the semidormant state of the beetles. From November until February only a few beetles are seen on the plants, but they may be located by searching in the mulch or dried leaves. In February many of the beetles come out of their hiding places and start feeding.

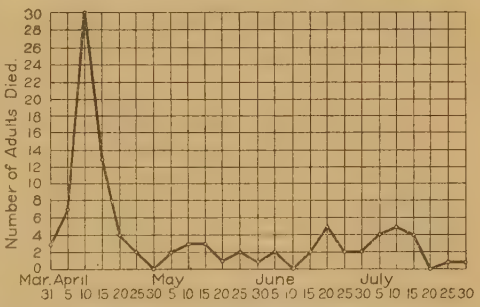

FIG. 10.—Time of death of 99 adults of the strawberry rootworm collected in greenhouses in March, 1922. Records every five days from March 26 to July 31

Very few beetles collected during March have lived until May, although a few have thrived until June and July. (Fig. 10.) Most adults collected in May and June have lived through the summer and fall months, and a few individuals have survived until December. Reference to Table 5 will show a general decrease in the number of collected adults during two general periods, April and May, and August and September.

Egg laying commences early in March, continuing through April and to a limited extent in May. From these eggs develops a new brood of adults which emerge from early May until late in July. The maximum number of beetles are found from late in June until August, which is also the period of severest injury to the plants. Many individuals of the second brood, which develops from eggs deposited by these beetles, and which emerges during September and October, live through the winter and lay eggs the following spring.

The generations are usually indistinctly separated, owing to the long period of egg deposition and the fact that a female may continue laying eggs after adults have developed from her earlier eggs. Frequently, even in severely infested greenhouses, there are periods when a comparative absence of adults may lead a grower to believe that some cultural or other method has successfully controlled the insect, but the emergence of a new brood of adults a few days later proves any decrease to have been merely seasonal. For example, on June

10 one grower believed he had rid his plants of the insects because he found only a few beetles and very little evidence of fresh feeding. Ten days later, however, large numbers of soft, light-colored adults, indicating recent emergence, were on the plants feeding voraciously. Such periods of comparative scarcity are of indefinite duration, and are more likely to occur in the intervals between broods, especially in May and June, and again in August and early September.

Eggs have not been found in greenhouses between September 1 and March 1. Soil examinations in September and October have shown only well-developed larvæ and pupæ; never any young larvæ. That the adults which emerge in the fall do not lay eggs until after the hibernating period is indicated in Table 12. It will also be seen that most of the eggs were deposited after February, even though a few were laid during December and January, owing possibly to cage conditions.

TABLE 12.—*Period of egg deposition of strawberry rootworm beetles collected from September, 1921, to January, 1922*

[Eggs were deposited by caged beetles from December, 1921, to March, 1922, although none were found in greenhouses in the same period]

Date	A 10 beetles		B 17 beetles		C 13 beetles		D 15 beetles		E 2 beetles		F 9 beetles	
	Alive	Eggs	Alive	Eggs	Alive	Eggs	Alive	Eggs	Alive	Eggs	Alive	Eggs
1921												
Aug. 31	[1] 10	0										
Sept. 12	10	0					[1] 15	0				
15	10	0	[1] 17	0			15	0				
Oct. 12	10	0	17	0	[1] 13	0	15	0				
27	9	0	9	0	11	0	14	0	[1] 2	0		
Nov. 10	6	0	7	0	9	0	14	0	1	0		
17	6	0	7	0	9	0	8	0	1	0		
23	5	0	7	0	9	0	5	0	1	0		
Dec. 5	5	0	4	1	9	0	5	0	1	0		
6	5	0	4	2	9	0	5	0	1	0		
13	5	0	4	0	9	0	3	0	1	0		
22	4	0	4	1	9	0	3	0	1	0		
24	4	0	4	27	9	0	3	0	1	0		
27	4	0	4	10	9	0	3	6	1	0		
29	4	0	3	10	9	4	3	0	1	0		
30	4	0	3	0	9	2	3	4	1	0		
31	4	0	3	0	8	0	3	0	1	0		
1922												
Jan. 3	3	0	3	0	7	3	3	10	1	0	[1] 9	0
5	2	0	3	2	6	0	3	0	1	0	9	0
Feb. 7	2	0	3	0	4	2	3	0	1	0	7	0
13	2	0	3	7	4	0	3	0	1	0	7	0
21	2	0	3	0	4	0	3	4	1	6	6	6
28	2	0	3	11	2	0	3	0	1	8	6	17
Mar 6	2	0	3	11	2	1	2	0	1	7	6	5
13	1	0	2	4	2	0	2	0	1	0	5	15
18	1	3	2	9	2	0	2	0	1	14	5	0
25	[2] 0	0	2	18	2	0	2	0	1	2	5	50
Apr. 1			1	0	2	0	[2] 0	0	1	0	3	4
8			1	0	2	0			1	0	2	26
15			1	0	2	0			1	0	2	19
24			1	0	2	4			1	0	2	15
29			[2] 0	0	2	0			1	0	2	0
May 6					2	0			1	0	2	0
13					2	5			1	0	2	0
20					1	11			1	25	[2] 0	0
27					1	0			1	0		
June 3					[2] 0	0			1	3		
10									[2] 0	0		
Total		3		113		32		24		65		157

[1] Date collected.

[2] Cage closed.

NATURAL ENEMIES

Natural enemies of the strawberry leaf beetle are apparently very few in the greenhouse, since no parasites have been observed attacking any of the several stages. Among the predators, carabid beetles and their immature stages are occasionally found in the soil and will devour any adults, larvæ, or pupæ which they may encounter by chance; these insects show no preference for *Paria canella*, however, and are not plentiful enough to render any practical assistance in control. Adults of Paria are often found bearing numbers of small mites, *Uropoda* sp., on their elytra. These mites are very prevalent in manure and soil, and it is probable that they use the beetles as transporting agents, since they have also been found attached to sowbugs and millipeds. Spiders and toads will eat adult beetles coming within their reach. In one packing room a large spider which had a web close to the sorting bench immediately attacked and killed all beetles carried in on cut flowers which were placed on a knife point within its reach. In the same room a large toad was observed to devour any of the beetles which dropped to the floor. None of these creatures, however, can be considered as an important factor in controlling this insect.

EXPERIMENTS IN CONTROL

Early in the progress of these investigations the futility of attempting to control the strawberry rootworm in greenhouses by methods normally employed against leaf-feeding insects was illustrated in Dietz's report on an infestation in Indiana, as published in a paper by Weigel and Chambers (*30*, *p. 227*). The roses had been sprayed several times with a mixture consisting of 2 pounds of powdered arsenate of lead and 12 teaspoonfuls of Paris green in 50 gallons of water. This solution did not adhere well and proved ineffective against the beetles. A commercial brand of kerosene emulsion, diluted 1 part to 16 parts of water, killed the adults by contact, but burned the leaves so severely that the injury was still visible five weeks later. Volatile nicotine at the rate of 36 teaspoonfuls to 4 gallons of water stupefied but failed to kill the beetles.

In 1920 the writer investigated an infestation in Cumberland, Ind., where he found that, as a result of the failure of all poison applications, the growers had resorted to hand picking the adults, using the specially constructed pan described on page 37.

Peterson (*23*, *pp. 479–493*), of New Jersey, and Primm and Trimble, of Pennsylvania, encountered similar difficulties, and as a last resort the florists concerned turned to the laborious but certain control by hand picking, in some cases using the special-pan method. When the first control experiments were undertaken at Alexandria, Va., a serious infestation existed, and the ravages of the insects were progressing at such an alarming rate that the entire crop was threatened. Since the roses at that season of the year were being forced because of favorable weather conditions, the control program necessarily had to be in accordance with the cultural methods in order not to prove deleterious to the future growth of the plants.

SPRAYING WITH ARSENICALS

Ordinarily arsenicals used as stomach poisons are the standard remedies applied in combating such ravenous leaf feeders. For this reason preliminary tests were made with varying strengths of calcium arsenate, arsenate of lead, and Paris green. In spraying the plants at Alexandria, Va., with a pressure sprayer, special care was taken to cover all of the foliage so that it presented a whitewashed appearance which lasted many days. The arsenates of lead and calcium did not injure the rose foliage when used at the rate of from 2 to 2½ pounds to 50 gallons of water, to which one-half ounce of soap was added for each gallon of spray material, provided they were applied only on bright days; otherwise severe burning resulted. This was demonstrated in experiments conducted later at Oak Lane, Pa., where one block of 40 rose bushes sprayed at the foregoing dilution on a dark, cloudy day showed severe burning and the plants shed 50 per cent of the foliage, whereas a similar group sprayed on the following day, which was clear, suffered no injury.

FIG. 11.—Rose plant cut back at end of resting period. Many adults were found hiding in the débris on the soil. (See fig. 14)

In marked contrast with the reported control of this insect on strawberry plants by means of spraying with calcium arsenate or lead arsenate, it was found that under the conditions existing in rose houses this treatment was not only impracticable and objectionable but was actually ineffective. It was impracticable because the beetles fed at night on the young and tender growth, which was being forced so rapidly during the hot, sultry nights that it could not be sprayed frequently enough to keep the new foliage covered with the poison. Moreover, the whitish deposit which remained on the leaves after spraying was objectionable to the florists, because it reduced the market value of the cut flowers. It was ineffective in controlling the beetles because they avoided feeding on the arsenate-coated foliage but continued to devour the new leaves.

There is, however, one period in the culture of roses when the use of an arsenical as a spray has proved effective against the beetles. When the rose plants are cut back (fig. 11) practically all the foliage is removed and the fresh growth develops from new buds. The absence of foliage forces the beetles to feed on the green bark as well as on the swelling and breaking eyes or buds, which causes

serious retardation of the growth. For about six weeks after the cut back, during which period no blooms are produced, the plants may be sprayed rather than dusted with arsenates to keep the foliage protected. When a solution of from 4 to 5 pounds of powdered arsenate of lead or calcium arsenate to 50 gallons of water, with soap added as a "sticker," was used to spray the stems and swelling buds the same day, so that the beetles found them covered with an arsenical, the plants in several infested rose houses passed this critical stage with almost no injury.

For several seasons one florist sprayed his plants with a Bordeaux-arsenate of lead mixture which served as a repellent in protecting them from the insects' voracious feeding at the time the plants were making their new growth after being cut back.

In the earlier experiments at Alexandria, Va., Paris green was soon rejected as a spray because no diminution in the numbers of adults was noticeable, even though the florist had been using it over the entire range of infested houses prior to tests by the Bureau of Entomology. No injury to the plants followed its application. But in Indiana its use at a greater strength failed to afford any relief from the work of the beetles. Peterson's (*23, p. 481*) observations made eight days after application indicated that Paris green at the rate of from 4 to 8 ounces to 50 gallons of water did not kill the adults in sufficient numbers to warrant its use, and that 8 ounces of Paris green to 50 gallons of water may burn rose foliage. Furthermore, it has been noticed during the last three seasons that although florists have occasionally felt certain that they had succeeded in controlling the strawberry leaf beetle by using Paris green, they have found it later continuing its ravages. From all this it is apparent that this treatment is ineffective.

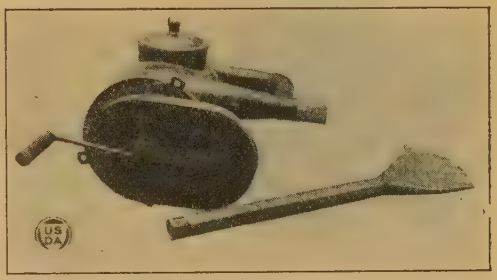

FIG. 12.—Fan type of hand duster, useful for applying insecticidal dusts in greenhouses

DUSTING WITH ARSENICALS

The deposit which remains on the leaves of rose plants after spraying with arsenicals is objectionable, because it impairs the ornamental value of the foliage. Attention was therefore directed to other means of application. A dust mixture containing 10 per cent, or preferably 15 per cent, of either lead arsenate or calcium arsenate and superfine sulphur or other carriers, applied with an improved hand duster of the fan (fig. 12) or the bellows (fig. 13) type, overcame this difficulty. The following formulas are recommended and may be purchased or mixed:

	Pounds
10 per cent formula:	
Superfine sulphur (200 mesh)	90
Lead arsenate or calcium arsenate (powdered)	10
15 per cent formula:	
Superfine sulphur (200 mesh)	85
Lead arsenate or calcium arsenate (powdered)	15

The use of this dust mixture is practical in greenhouses, because the foliage can be easily and quickly covered with the arsenical without being injured or disfigured by it, and the sulphur in it also operates against mildew and black spot. Eight pounds of the dust can be applied to 3,000 plants 2 to 3 feet tall in less than eight minutes. Because of its relatively nonsticking quality, the dust covering is washed from the foliage and must be renewed after each syringing, or about two or three times a week. By this means the new growth produced in the periods between dusting is also kept covered. From the middle of February, when the beetles begin feeding, until November, when they become inactive, the leaves must be constantly covered with an arsenical to protect them from injury.

It was not possible to determine with accuracy the effect of these dusts when applied on a commercial scale in the greenhouses, unless diminution of numbers be used as an index. The results presented in Table 13, however, indicate the effect of various mixtures on caged beetles.

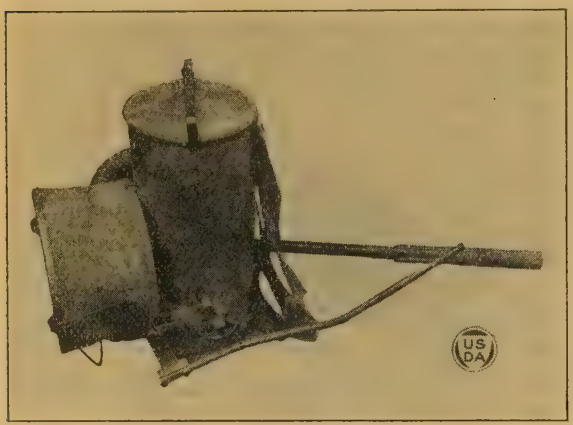

FIG. 13.—Bellows type of hand duster, useful for applying insecticidal dusts in greenhouses

The outstanding fact in the cages where arsenicals were used is the very greatly reduced amount of feeding as compared with the foliage consumed in the check cages, and this indicates a repellent action in addition to the poisonous effect when eaten in larger quantities. In some cages the arsenicals seem to affect the beetles almost immediately, whereas in others the action appeared to be prolonged over several days. The amount of feeding on leaves dusted with superfine sulphur was somewhat reduced, but did not result fatally. There was no evidence that the effectiveness of dusts would be increased by the addition of cornstarch as a possible bait. Hellebore proved valueless. Beetles which were caged with untreated rose leaves ate voraciously, while others confined without food remained alive from 7 to 15 days.

In three establishments which had suffered severe injury dusts were applied during three seasons. In two of these places the plants were treated persistently and thoroughly with a mixture of lead arsenate and sulphur (10 per cent formula) during the periods when the beetles were present in large numbers. Although many of these insects were actually removed by tearing out infested beds, by replacing the soil, by setting new plants, and by hand picking, the dusting was undoubtedly a very important factor in reducing the infestation in these establishments.

TABLE 13.—*Experiments with arsenical dusts on caged strawberry rootworm beetles*

[Five beetles were used in each experiment]

Material and strength	First day		Second day		Third day		Fourth day		Fifth day	
	Dead	Feeding punctures	Dead	Feeding punctures	Dead	Feeding punctures	Dead	Feeding punctures	Dead	Feeding punctures
Sulphur 90 parts, Arsenate of lead 10 parts	1	10	3	8	0	3	1	0	------	-------
Sulphur 90 parts, Arsenate of lead 10 parts	0	4	0	1	1	5	0	3	1	0
Sulphur 90 parts, Arsenate of lead 10 parts	0	9	0	9	0	0	0	0	1	0
Sulphur 80 parts, Arsenate of lead 20 parts	0	9	1	12	2	1	0	2	2	0
Sulphur 80 parts, Arsenate of lead 20 parts	5	1	------	-------	------	-------	------	-------	------	-------
Sulphur 80 parts, Arsenate of lead 20 parts	0	0	1	1	0	3	0	0	3	1
Sulphur 80 parts, Arsenate of lead 10 parts, Bordeaux, dry 10 parts	0	11	3	0	------	-------	------	-------	------	-------
Sulphur 50 parts, Arsenate of lead 10 parts, Kaolin 40 parts	0	0	0	6	2	3	0	0	3	1
Sulphur 80 parts, Arsenate of lead 15 parts, Powdered sugar 5 parts	0	1	0	3	0	0	0	0	0	0
Arsenate of lead, pure	3	4	2	2	------	-------	------	-------	------	-------
Sulphur 90 parts, Calcium arsenate 10 parts	1	3	3	0	1	0	------	-------	------	-------
Sulphur 90 parts, Calcium arsenate 10 parts	0	1	0	6	0	5	0	0	4	3
Sulphur 80 parts, Calcium arsenate 20 parts	0	2	1	1	2	0	1	0	1	0
Sulphur 80 parts, Calcium arsenate 20 parts	0	1	0	0	3	2	0	0	2	1
Calcium arsenate 2 pounds, Water 50 gallons	1	3	3	3	0	0	1	0	------	-------
Sulphur 50 parts, Calcium arsenate 10 parts, Kaolin 40 parts	0	1	0	2	1	1	0	0	2	1
Sulphur 72 parts, Arsenate of lead 18 parts, Cornstarch 10 parts	0	3	0	3	0	5	0	0	0	0
Sulphur 81 parts, Arsenate of lead 9 parts, Cornstarch 10 parts	0	3	0	3	0	2	0	0	------	-------
Hellebore, dry	0	24	0	20	0	6	0	7	0	0
Sulphur, pure	0	18	0	13	0	8	1	4	(1)	(1)
Check (untreated leaf)	0	52	0	36	0	26	0	15	(1)	(1)
Do	0	0	0	65	0	50	0	0	0	91
Do	0	0	0	0	0	25	1	19	0	0
Check (no food, 14 beetles)	0	-------	0	-------	0	-------	0	-------	0	-------

[1] No data.

TABLE 13.—*Experiments with arsenical dusts on caged strawberry rootworm beetles*—Continued

Material and strength	Sixth day		Seventh day		Total		Control	Remarks
	Dead	Feeding punctures	Dead	Feeding punctures	Dead	Feeding punctures		
							Per cent	
Sulphur 90 parts, Arsenate of lead 10 parts					5	21	100	
Sulphur 90 parts, Arsenate of lead 10 parts	0	0	2	0	4	13	80	1 alive.
Sulphur 90 parts, Arsenate of lead 10 parts	0	0	2	0	3	18	60	1 dead on eighth day, 1 dead on ninth day.
Sulphur 80 parts, Arsenate of lead 20 parts					5	24	100	
Sulphur 80 parts, Arsenate of lead 20 parts					5	1	100	
Sulphur 80 parts, Arsenate of lead 20 parts	1	0			5	5	100	
Sulphur 80 parts, Arsenate of lead 10 parts, Bordeaux, dry 10 parts					3	11	60	2 escaped.
Sulphur 50 parts, Arsenate of lead 10 parts, Kaolin 40 parts					5	10	100	
Sulphur 80 parts, Arsenate of lead 15 parts, Powdered sugar 5 parts	0	6	0	1	0	11	0	1 died on eleventh day.
Arsenate of lead, pure					5	6	100	
Sulphur 90 parts, Calcium arsenate 10 parts					5	3	100	
Sulphur 90 parts, Calcium arsenate 10 parts	1	0			5	15	100	
Sulphur 80 parts, Calcium arsenate 20 parts					5	3	100	
Sulphur 80 parts, Calcium arsenate 20 parts					5	4	100	
Calcium arsenate 2 pounds, Water 50 gallons					5	6	100	Solution sprayed.
Sulphur 50 parts, Calcium arsenate 10 parts, Kaolin 40 parts	2	0			5	5	100	
Sulphur 72 parts, Arsenate of lead 18 parts, Cornstarch 10 parts	0	5			0	16	0	3 died on eleventh day.
Sulphur 81 parts, Arsenate of lead 9 parts, Cornstarch 10 parts					0	8	0	1 died on eleventh day.
Hellebore, dry	0	0			0	57	0	Fresh untreated leaf given on sixth day.
Sulphur, pure	(1)	(1)	(1)	(1)	1	43	20	
Check (untreated leaf)	(1)	(1)	(1)	(1)	0	129	0	
Do	0	36	0	27	0	269	0	New leaf given on fifth day.
Do	(1)	(1)	(1)	(1)	1	44	20	
Check (no food, 14 beetles)	0		2		2	0	40	All dead on fifteenth day.

[1] No data.

In the third establishment dusting was practiced to only a limited extent during 1920. In 1921 a heavy infestation existed and dusting was employed as one of several methods of controlling the beetles. After the plants had started new growth following the cut-back period (fig. 14), they were kept continually dusted until the middle of November, at which time very few beetles were to be found, and it was supposed that they were in their usual inactive state for the winter. For the first month the sulphur-arsenate of lead (10 per cent) mixture previously mentioned was applied, and after that the following dust mixture was used:

	Pounds
Superfine sulphur (200 mesh)	80
Calcium arsenate	15
Powdered sugar	5

The powdered sugar was added in the hope that it might prove attractive as a bait, and the arsenical content was increased on the theory that it would be more effective than the 10 per cent mixture. The dust was applied in accordance with the florists' program, i. e., after each syringing, or about two or three times weekly, so that from midsummer until November about 1,500 pounds of this material were used in keeping the foliage covered. During 1922 the insects failed to appear in appreciable numbers, and this infestation was found to be so very materially diminished that it became practically negligible. As a precautionary measure, however, a dust coating was maintained on the foliage from February 15 until the plants were cut back or torn out in the summer. As was the case in the first two establishments, other control measures were employed also, and reliance was not placed on dusting alone in combating the beetles.

FIG. 14.—Growth made by plant four weeks after being cut back. (See fig. 11)

It was unfortunate that the effectiveness of dusts alone, uncomplicated by other simultaneous methods of control, could not have been tested in a commercial range; but the fact that dusting with arsenicals was the principal control measure common to all three establishments, with the possible exception of a limited amount of hand picking, indicated that this treatment was an important factor in reducing these infestations. The florists who used this dust felt well satisfied with the results obtained from an insecticidal view-point, and because of the fungicidal value of the sulphur in the mixture.

FUMIGATION

The use of one of the standard fumigants, such as hydrocyanic-acid gas and volatile nicotine, which are frequently employed in greenhouse fumigation (fig. 15), was given consideration early in this investigation. According to several florists the use of volatile nicotine painted on pipes was entirely ineffective against the beetles (*25, p. 70*), and subsequent experiments verified this conclusion. In the case of hydrocyanic-acid gas it was necessary to determine the

killing strength for the beetles and then to test the advisability of using such measures on young and tender growth. For this purpose preliminary experiments were carried out, in which from one-fourth ounce to 2 ounces of sodium cyanide per 1,000 cubic feet of space was used. The results demonstrated that the adults could be killed by fumigation at night with a 1½ to 2-ounce dosage of the sodium cyanide[7] and an exposure lasting two hours.

FIG. 15.—Greenhouse prepared for fumigation with hydrocyanic-acid gas

After the first commercial test in which a killing dosage was used, an examination of the fumigated houses at 8.30 o'clock the next morning showed the following results: Large numbers of the beetles were found exposed on the surface of the foliage, lying on their backs and sides. Many were killed in the act of feeding, while others could be found lying on the surface of the soil and under-

[7] A 1–1½–3 formula was used, which required 1½ fluid ounces of sulphuric acid (about 1.84 sp. gr.), 3 fluid ounces of water, and 1 ounce of sodium cyanide (containing approximately 51 per cent cyanogen) for each 1,000 cubic feet of space in the house. This was a slight divergence from the 1–1½–2 formula, and it was adopted in order to insure a more complete generation and equal distribution of the gas by providing a sufficient amount of dilute acid to submerge the cyanide, particularly in cases where only small quantities of the chemicals were being used in each generator. The quantities of materials used at the respective rates of 1½ and 2 ounces of sodium cyanide per 1,000 cubic feet were as follows:

Sodium cyanide	1½ ounces.
Sulphuric acid	2¼ fluid ounces.
Water	4½ fluid ounces.
Sodium cyanide	2 ounces.
Sulphuric acid	3 fluid ounces.
Water	6 fluid ounces.

Further directions for the use of this gas are contained in Farmers' Bulletin 880, entitled "Fumigation of Ornamental Greenhouse Plants with Hydrocyanic-Acid Gas," which may be obtained by applying to the Office of Publications, U. S. Department of Agriculture.

neath the plants. Because of the fact that the adults showed a marked tendency to feign death, 317 were collected and held in cages several days for further observations. Less than 3 per cent of these revived, and a total mortality of 97 per cent was therefore obtained from this fumigation. It is advisable to emphasize the fact that although fumigation at this strength and duration is contrary to the general recommendations for fumigating greenhouses, it is an effective though very drastic means of checking the ravages of the beetles in severe infestations. Moreover, by destroying the females at this time further egg laying is precluded and subsequent infestation thereby reduced.

As had been anticipated, some of the young and tender growth was burned, thus depriving the few remaining adults of their favorite feeding places. This injury, however, was only temporary, for three weeks later the plants had produced an abundance of newly forced growth, attributed to the stimulating effect which usually follows fumigation with hydrocyanic-acid gas, and were in excellent condition. During the subsequent months these plants produced a bountiful crop of cut flowers in comparison with the very inferior production prior to the fumigation.

In one establishment during the summer of 1921 approximately 32,000 plants, including 1,000 newly set young plants in the resting or drying-off period, were fumigated at a dosage of 2 ounces of sodium cyanide per 1,000 cubic feet of space, with an exposure lasting one and one-half to two hours, at temperatures ranging from 66 to 88° F., and not one plant was lost or even retarded in general growth (*31, p. 230*). The anticipated burning on the tender growth proved to be a negligible factor, since it was removed by the severe pruning when the plants were cut back. The results of the experiments, together with similar ones carried on at Alexandria, Va., and Baltimore, Md., are given in detail in Table 14. As will be observed, several houses received three or four successive fumigations. Moreover, these tests demonstrated on a practical scale that muslin curtains (fig. 16) could be used successfully to confine the gas in any section of an open-range house.

During the last three seasons 21 commercial houses, involving many thousands of plants, have been fumigated with consistent results, demonstrating the successful use of this gas on a practical and commercial scale for controlling the adult beetles.

Since a series of three or more successive fumigations with hydrocyanic-acid gas at night, at the rate of 1½ or 2 ounces of sodium cyanide per 1,000 cubic feet of space, with an exposure lasting two hours, at intervals of three or four days during the drying-off period, and with the final fumigation the night before the plants are cut back, kills all adults above the ground without permanent injury to the plants, fits in with the cultural practice in the summer when the beetles are most numerous, and may be applied in individual sections of open-range houses by separating them with muslin curtains, canvas, or oiled paper to confine the gas, it is without doubt one of the most effective and satisfactory means of destroying the beetles.

TABLE 14.—*Effects on strawberry rootworm beetles and rose plants of fumigating infested rose houses with hydrocyanic-acid gas*

Date	Contents of house	Number of plants	Sodium cyanide per 1,000 cubic feet	Exposure	Temperatures		Relative humidity	Control [1]	Effect on plants	Remarks
					Inside	Outside				
1919	*Cubic feet*		*Ounces*	*Hours*	° *F.*	° *F.*	*Per cent*	*Per cent*		
July 30	146,000	----------	½	2	78	----------	85	0	No burning	Ineffective.
31	146,315	----------	2	2	----------	----------	----------	97	Young growth burned	
Aug. 1	78,412	----------	2	2	77	----------	91	97	----do	
1	114,061	----------	1½	2	75	----------	92	97	----do	
1920										
June 2	146,000	----------	2	14	----------	----------	----------	100	All foliage burned	Roots washed, plants cut back and used in other houses. Very healthy and thriving.
1921										
July 8	34,612	2,500	2	1¾	85	80	----------	97	Young growth burned	
15	[2] 34,612	2,500	1½	1¾	78	76	----------	97	----do	2 successive fumigations.
11	47,449	3,600	2	2	76	75	----------	97	----do	
12	47,449	3,600	2	2	75	72	----------	97	----do	
15	[2] 47,449	3,600	1½	1¾	78	76	----------	97	----do	3 successive fumigations.
11	30,408	3,000	2	1¾	75	75	----------	97	----do	
18	[2] 30,408	3,000	2	1½	76	75	----------	97	----do	
20	[2] 30,408	3,000	2	1¾	72	72	----------	97	----do	4 successive fumigations.
29	[2] 30,408	3,000	2	2	73	71	----------	97	----do	
18	108,536	7,300	2	1½	76	75	----------	97	----do	
20	108,536	7,300	2	1¾	72	72	----------	97	Young plants slightly injured	Injury offset by stimulation in new growth.
21	[2] 33,299	2,800	1¾	1¾	71	70	----------	97	----do	Do.
27	[2] 79,488	6,400	2	2	84	83	----------	97	Young growth burned	
Aug. 2	[2] 59,823	4,100	2	2	66	62	----------	97	----do	
8	[2] 19,844	1,500	2	10	69	68	----------	97	----do	
1922										
July 28	188,100	----------	1½	1	81	----------	91	97	----do	

[1] The figures on which the percentages of control are based are omitted in this table, the main purpose of the table being to demonstrate that the injury to the plants by the gas was only temporary and that they soon recovered.

[2] Muslin curtains used to separate house to be fumigated from others.

HAND PICKING

Many florists, failing to control the beetles with sprays, fumigants, or traditional "cures," had recourse to hand picking as a last resort, thus assuring themselves of the positive removal from consideration of all beetles collected and killed. In some establishments the workers merely collected the beetles visible on the plants, sometimes using ordinary pans. Others devised more thorough methods, such as beating the plants with a stick in order to jar the beetles into a pan held between the crossrows. For this purpose they used a special pan about 3 feet deep, wide enough to span the bench, and which had the lower ends rounded to reach underneath the plants. Oil was kept in the bottom of the pans to kill the beetles coming in

FIG. 16.—Muslin curtains used to separate sections of an open range of greenhouses during fumigation with hydrocyanic-acid gas

contact with it. Paddles covered with sticky fly paper served a similar purpose.

These methods were very effective, particularly when the beetles were gathered on the "bleeding" ends of the cut-back plants (fig. 11), where they were plainly visible. In one greenhouse where the plants had been cut back in April over 1,000 beetles were collected on 3,000 plants, even though they were not very numerous because the new brood had not yet begun to appear.

In another place, where no other control measures were practiced, the workmen took advantage of the adults' habit of climbing the wire supports after the plants had been syringed, by spending an hour after this operation each day in collecting and killing the beetles. Large numbers were thus disposed of. This method was followed diligently day after day throughout September and October of 1921, when many adults were present. Cleanliness was also prac-

ticed by keeping the beds free from dried leaves and applying no mulch. In the spring of 1922, despite a continued and careful search, only a few scattered beetles were found and the greenhouse was practically free from infestation. Undoubtedly the constant hand picking had resulted in a great decrease in the numbers of beetles of the overwintering brood.

In one instance a modification of the hand-picking method was advised, which resulted in a greater efficiency because of the greatly reduced labor required. It is customary among rose growers to water the plants so heavily every three or four days that the water collects in puddles or pools on the surface of the bed, from which it gradually drains off. Where heavy infestations exist the beetles are dislodged and thrown to the ground during the syringing and watering, and on landing in the water they make vigorous efforts to reach the nearest plant or other object on which to make their escape. Various growers took advantage of this habit by having the gardeners follow the man who watered the plants to collect all floating or swimming beetles possible. In a very short time as many as 1,000 beetles were gathered from three beds of roses.

Although this method of warfare is crude and only partially effective, it appealed to the florists, and for this reason efforts were directed toward improving the practice by "filming" the surface of the flood water with a contact insecticide, such as kerosene nicotine oleate.[8]

Spraying the insects on the plants with the same solution proved ineffective, because of their hard wing covers and body. The success of this treatment therefore depended on the beetles swimming through the poison so that it came in direct contact with the softer body parts under the wing covers. Preliminary tests were made with one-half pint of kerosene nicotine oleate stock solution diluted with 4 gallons of water. This solution was applied over about 6 square feet of surface by means of a sprinkling can, and the results were promising. Applied in this manner the insecticide was greatly diluted by filming and spreading over the water surface; nevertheless its effect on the beetles was apparent almost immediately after they came in contact with it.

Fourteen beetles were collected and held for observation. Seven of them had been subjected to this treatment, whereas the others had merely been washed from the plants by the force of the water. Two days later the treated specimens were dead and the "checks" were still alive. Three days after the preliminary test 7,000 plants in one large range were treated. Specimens of the treated beetles kept

[8] Kerosene nicotine oleate stock solution is prepared as follows and is a slight modification of William Moore's original formula.

Stock solution:

Solution 1—	
Kerosene	8 parts or 1 gallon.
Oleic acid	1 part or 1 pint.
Solution 2—	
Volatile nicotine	2 parts or 2 pints.
Water	8 parts or 1 gallon.

Solution 1 is prepared by slowly pouring the oleic acid into the kerosene, stirring constantly. In another vessel solution 2 is made up by adding the volatile nicotine to the water. The stock solution is then prepared by stirring solution 1 into solution 2 and bringing the mixture to a creamy consistency by churning it rapidly for several minutes, pouring from one vessel to the other, or pumping the liquid back upon itself through a bucket pump.

under observation succumbed shortly thereafter, thus corroborating the earlier results. Other extensive tests were tried on a total of about 20,000 bushes with the same degree of effectiveness.

This treatment therefore finds convenient application, especially when the new growth has started after the resting period, and in the fall when it would be inadvisable to employ other remedies, such as fumigation or spraying. Furthermore, every adult killed then would mean so many less the following spring.

SCRAPING THE SOIL OF BEDS

It is a cultural practice among rose growers to scrape off 1 or 2 inches of the loose, dry surface soil from the beds during the drying-off period immediately after the plants have been cut back. The soil is then thoroughly soaked with water, bone meal is applied as a fertilizer, and a mixture of well-rotted manure and composted soil is used to replace the removed layer. Certain modifications of this method, such as making deep furrows between crossrows of plants and filling them with manure, are also used.

Examination of the material removed from infested beds disclosed 30 adults in the soil surrounding 6 plants, and in another place 14 were found near 3 plants. Their prevalence at this time suggests a practical means of destroying many beetles by shaking the plants and by removing the soil from the house and treating it as soon as the plants have been cut back. Unless this is done at once, however, the beetles will severely injure the plants by devouring the buds and girdling the stems.

CLEAN CULTURE

In a certain establishment already discussed under hand picking it was customary to keep the beds immaculately clean and to apply liquid manure instead of a mulch to the soil. At all times the beds were kept free from dead leaves and débris by the workmen, who removed them at frequent intervals and burned them. These beds had the appearance of having been swept with a broom. Undoubtedly this practice contributed much toward reducing the infestation, not only by removing many beetles and preventing the remainder from hiding in the dead leaves over winter but also by decreasing proportionately the amount of egg deposition in the spring. Moreover, it prevented many newly hatched larvæ from reaching the soil. From February until September the leaves should be removed every 10 days in order to destroy the eggs in them. In heavy infestations it is desirable to fertilize the beds with liquid manure instead of mulching.

SOIL TREATMENT

Since the larva and pupa stages, requiring about six to eight weeks for their development, are spent in the soil, they appeared to furnish a period when the insects would be susceptible to control by means of soil treatments. During the first season efforts were therefore directed primarily toward finding some soil application, either an insecticide or a fertilizer, which would operate against these stages and hence prevent the emergence of the adults. With this object in

mind the following materials were tested during the season of 1920 by E. L. Chambers:

(1) Carbon disulphide: 5 to 25 cubic centimeters injected between bushes approximately 14 inches apart.
(2) Carbon disulphide in solution: One-fourth to one-half ounce dissolved in 4 gallons of water applied to 24 square feet.
(3) Sodium cyanide in solution: One-eighth to one-half ounce per gallon of water applied to 6 square feet.
(4) Cyanamide: One-half pound to 2 pounds to 40 square feet.
(5) Acid phosphate: 200 pounds to 1,200 square feet.
(6) Wood ashes: 200 pounds to 1,200 square feet.
(7) Tobacco dust: 200 pounds to 1,200 square feet.
(8) Hydrated lime: 200 pounds to 1,200 square feet.

These materials were applied over large areas, but no counts were made which would indicate accurately the mortality of the larvæ and pupæ resulting from their use. Although in some instances apparent diminution in number was noted, it could not be definitely associated with any particular treatments.

During 1921 in wholesale rose houses at Doylestown, Pa., a solid bed containing approximately 800 plants, which had been growing there for eight years, afforded an excellent opportunity for further experimental work. These plants were very heavily infested, and in some cases had as many as 23 larvæ and pupæ around the roots of a single plant.

Preliminary tests with various chemicals were made with potted rose plants, in the soil of which a definite number of larvæ and pupæ had been buried at their normal depth of 2 inches. The results are presented in Table 15.

Thirty-nine experiments, based on the results obtained from these preliminary tests, were then conducted in the infested beds on plots containing from 5 to 25 plants each. At approximately five-day intervals examinations of the treated and the check plants were made by digging them up and examining the roots and surrounding soil for the larvæ and pupæ. Thus observations were made on the effectiveness of the materials used as well as on the minimum time required for them to exert their insecticidal action.

The results of these experiments indicated that orthodichlorobenzene and kerosene nicotine oleate emulsion might prove satisfactory in practical tests. These materials were therefore applied in plots in the ground bed. Orthodichlorobenzene used in three plots at the respective rates of 1, 2, and 3 cubic centimeters per plant produced mortalities of 36 per cent, 26 per cent, and 52 per cent, respectively. Injury to the plants, however, was so pronounced, even before they were removed for examination, that the use of this chemical is precluded. Five plots containing 45 plants were treated with kerosene nicotine oleate emulsion in varying dilutions. This material proved unsatisfactory and was removed from further consideration, because it left the soil in a greasy and objectionable condition. Mercuric chloride used at the rate of one-half ounce dissolved in 3 gallons of water was tried in a pot experiment and on a plot of 15 plants, where it proved entirely ineffective. The use of wood ashes and tobacco dust was tested further in plot experiments and is discussed on page 43.

TABLE 15.—*Effect against the strawberry rootworm of miscellaneous treatments on larvæ and pupæ in soil of potted rose plants*

Material and amount per plant	Number of—		Period after treatment	Condition when examined							
				Larvæ				Pupæ			
	Larvæ	Pupæ		Dead	Alive	Missing	Control	Dead	Alive	Missing	Control
			Days				*P. ct.*				*P. ct.*
Borax, 1 gram in ½ pint water [1]	20	0	5	1	7	11	5	0	1	0	0
Borax, 2 grams in ½ pint water [2]	20	0	5	0	3	17	0	0	0	0	0
Orthodichlorobenzene, 3 c. c.[3]	20	10	5	20	0	0	100	10	0	0	100
Mercuric chloride (1–800), ½ pint [2]	40	5	3	0	17	23	0	0	0	5	0
Wood ashes, soil covered ½ inch deep [4]	10	0	9	0	3	5	0	0	2	0	0
Do.[5]	10	10	6	0	8	2	0	2	7	1	20
Tobacco dust, soil covered ½ inch deep [2]	10	10	6	0	3	7	0	0	1	9	0
Lye (sodium hydroxide), 1 teaspoonful in ½ pint water [5]	10	0	5	3	6	1	30	0	0	0	0
Lye (sodium hydroxide), 1 teaspoonful dry and then watered [6]	10	0	5	5	5	0	50	0	0	0	0
Nicotine sulphate, 2 drops in 225 c. c. water [3]	10	0	5	0	1	9	0	0	0	0	0
Kerosene nicotine oleate, 8 c. c. in 250 c. c. water [6]	20	10	5	12	0	8	60	5	0	5	50
Kerosene nicotine oleate, 16 c. c. in 250 c. c. water [3]	20	10	5	18	0	2	90	9	0	1	90
Checks (no treatment)	20	10	5	0	9	11	0	1	0	9	10
Do	20	7	5	0	1	19	0	0	0	7	0
Do	43	5	5	0	4	39	0	0	0	5	0
Do	9	4	5	0	6	3	0	0	2	2	0

[1] One larva pupated.
[2] Ineffective.
[3] Effective.
[4] Two larvæ pupated.
[5] Slightly effective.
[6] Fairly effective.

TABLE 16.—*Effects of paradichlorobenzene soil treatments on larvæ and pupæ of the strawberry rootworm buried in pots*

Amount of material	Number of—		Period after treatment	Condition when examined							
				Larvæ				Pupæ			
	Larvæ	Pupæ		Dead	Alive	Missing	Control	Dead	Alive	Missing	Control
Grams			*Days*				*Per cent*				*Per cent*
2	25	10	6	24	0	1	96	10	0	0	100
3	25	10	6	25	0	0	100	10	0	0	100
4	10	0	5	5	0	5	50	0	0	0	0
4	20	0	6	17	0	3	85	0	0	0	0
8	10	4	5	6	0	4	60	4	0	0	100

The results obtained with paradichlorobenzene in preliminary tests were so satisfactory (see Table 16) that this material was used in 15 plots in an infested bed. In 10 of these the larvæ and pupæ were counted and their condition was noted in order to determine the insecticidal effect of this chemical. These data are presented in Table 17.

TABLE 17.—*Results of plot experiments with paradichlorobenzene against larvæ and pupæ of the strawberry rootworm*

Dosage	Period after treatment	Number of plants	Number of larvæ and pupæ		Control	Average control	Dosage	Period after treatment	Number of plants	Number of larvæ and pupæ		Control	Average control
			Examined	Dead						Examined	Dead		
Ounce	*Days*				*Per cent*	*Per cent*	*Ounce*	*Days*				*Per cent*	*Per cent*
0.2	6	2	10	6	60.0	45.9	0.4	6	2	15	9	60.0	88.8
0.2	10	3	27	11	40.7		0.4	7	7	35	32	91.4	
0.25	5	5	69	53	76.8	80.5	0.4	9	7	20	20	100.0	
0.25	10	5	27	24	88.9		0.4	10	3	19	18	94.7	
0.25	14	5	22	18	81.8		0.5	5	3	19	16	84.2	79.2
0.3	6	2	20	5	25.0	76.3	0.5	6	2	15	8	53.3	
0.3	7	7	24	22	91.7		0.5	10	6	31	25	80.6	
0.3	9	7	25	23	92.0		0.5	13	4	12	12	100.0	
0.3	10	3	28	24	85.7		0.6	6	2	10	8	80.0	92.9
0.375	5	5	32	25	78.1	85.2	0.6	10	3	18	18	100.0	
0.375	10	5	39	35	89.7								
0.375	13	5	10	9	90.0								

To determine plant tolerance of paradichlorobenzene it was also applied to plants in five plots which were receiving the regular cultural treatment accorded roses. The crystals were placed around the base of the plant and covered with soil. At the end of 10 days to two weeks they were removed from some plants but were left around the others until vaporized. The results were not satisfactory in either case. Even in the cases where the crystals had been removed and the lowest strength—one-fourth ounce per plant—was used, the bushes gradually declined in vigor and eventually died.

SODIUM CYANIDE

Sodium cyanide in solution was tried during the season of 1920, but sufficient data on the mortality of the larvæ and pupæ were not obtained at that time. Pronounced stimulation of root growth, with a corresponding increase in terminal growth, had been observed repeatedly to result from light dosages of this material. This treatment would therefore be desirable because of its stimulating effect on the plants, provided it was also effective in killing the soil stages of this insect.

TABLE 18.—*Effects of sodium cyanide in solution on larvæ and pupæ of the strawberry rootworm in pot experiments*

Amount of sodium cyanide in one-half pint water	Number of—		Condition 5 days after treatment							
			Larvæ				Pupæ			
	Larvæ	Pupæ	Dead	Alive	Missing	Control	Dead	Alive	Missing	Control
Grams						*Per cent*				*Per cent*
0.45	20	10	17	0	3	85	8	0	2	80
0.89	20	10	17	0	3	85	6	0	4	60
1.33	20	10	18	0	2	90	10	0	0	100
1.77	20	10	20	0	0	100	9	1	0	90

As shown in Table 18, the mortality in the preliminary pot experiments was promising, hence nine plots of five or six plants each were treated with sodium cyanide in solution. Sodium cyanide was also pulverized and then spread around the base of every plant in three plots of five plants each. The mortalities resulting from these plot treatments are listed in Table 19.

TABLE 19.—*Results obtained in plot experiments with sodium cyanide, in solution and pulverized, against larvæ and pupæ of the strawberry rootworm*

Dosage	Period after treatment	Number of plants	Number of larvæ and pupæ		Control	Dosage	Period after treatment	Number of plants	Number of larvæ and pupæ		Control
			Examined	Dead					Examined	Dead	
Grams	*Days*				*Per cent*	*Grams*	*Days*				*Per cent*
0.5	4	7	57	4	7.0	2	6	3	18	9	50.0
0.5	7	4	11	1	9.1	3	2	2	24	21	87.5
0.75	4	4	28	4	14.3	3	6	3	20	13	65.0
0.75	7	4	15	3	20.0	5	2	2	25	24	96.0
0.75	8	3	17	1	5.9	5	6	3	21	11	52.4
1	4	4	35	4	11.4	2[1]	8	5	16	4	25.0
1	8	7	57	7	12.3	3[1]	8	5	37	26	70.3
2	2	2	19	3	15.8	5[1]	8	5	21	20	95.2

[1] Applied in pulverized form.

In these experiments the mortality of larvæ and pupæ in soil which had been drenched with sodium cyanide was insufficient to justify its use as a means of destroying the soil stages. Moreover, the practical use of the pulverized crystals would be precluded because the collars of the plants were severely injured by this treatment.

WOOD ASHES AND TOBACCO DUST

Because of their fertilizing value, wood ashes and tobacco dust, but especially the wood ashes, are used extensively by florists. It was thought that the free lye present in wood ashes, and the nicotine, which is an ingredient of the tobacco dust, might leach into the soil and be effective in killing the larvæ and pupæ. To determine its effectiveness in three plots containing 10 plants each, a handful of this mixture was applied around the base of each plant and then watered. Examinations of the larvæ and pupæ in soil around the plants were made seven or eight days later, and the results are given in Table 20.

TABLE 20.—*Effects on strawberry rootworm larvæ and pupæ in soil treated with tobacco dust and wood ashes*

Material	Period after treatment	Number of larvæ		Control	Number of pupæ		Control	Larvæ and pupæ control
		Examined	Dead		Examined	Dead		
	Days			*Per cent*			*Per cent*	*Per cent*
Tobacco dust	7	44	4	9.1	41	9	22.0	15.3
Wood ashes	8	36	2	5.5	33	7	21.2	13.0
Tobacco dust and wood ashes mixed	7	17	2	11.8	18	2	11.1	11.4

The foregoing figures were based on only one treatment, whereas the maximum insecticidal effect could be obtained only by continuous leaching of these materials over an extended period, which would necessitate several successive applications.

In an establishment containing 40,000 rose plants two carloads of each of these materials were used during the spring of 1922. The mixture was applied on the soil several times at intervals of about two weeks. Occasional soil examinations during the season disclosed very few larvæ and pupæ. The balls of soil around the roots of 293 plants were examined and the larval and pupal stages infesting 19 of them were counted. Nine larvæ, ten pupæ, and one newly emerged adult were found, and all were alive. Several other control measures were also being practiced, however, and it is therefore a matter of conjecture whether the lightness of this infestation can be credited entirely to the use of the wood ashes and tobacco dust treatment.

Other experiments were performed to determine the effect on newly hatched larvæ of tobacco dust containing not less than one-half of 1 per cent of nicotine. A layer of this dust one-fourth inch deep was spread over the entire surface of the soil in flowerpots every two weeks. In some cases this treatment was followed by watering. All larvæ which were removed from egg cages immediately after hatching and placed on the treated surfaces died in a short time, whereas larvæ placed in a vial on untreated soil immediately showed greater activity by boring down below the surface in a lively manner.

These experiments indicate that a layer of tobacco dust on the soil from March to September, and the subsequent leaching of this material when larvæ are hatching and dropping to the ground, aids in the control of an infestation.

Since the rose plant can not tolerate heavy applications of wood ashes, it was found sufficient to use a handful per plant every two or three weeks.

PREVENTIVE MEASURES

Several preventive measures may be practiced to keep rose houses free from infestation with the strawberry rootworm. The fact has been established that some houses have become infested with the larvæ and pupæ of this insect by filling the beds with soil in which strawberry plants have been growing. In order to destroy these stages the soil should either be composted for several months or be sterilized before it is used. It is desirable to avoid using soil in which strawberry plants have recently been grown. Propagate young plants in separate houses free from the insects, and under no conditions expose them to contamination by proximity to infested beds or houses. In purchasing plants be certain that they are free from all stages of this pest, and that all precautions have been taken by the propagator to protect them. Keep the greenhouse free from rubbish and burn all dead leaves and débris removed from the beds, as well as the tops of the bushes which are removed when cut back. The importance of such precautionary measures is too frequently underestimated, and due consideration must be accorded them for preventing insects from gaining a foothold in greenhouses.

Observations have shown that plants retained in beds for three years or longer are usually the more heavily infested. By removing the plants and soil at the end of three years at the latest, the chances of severe infestation are very much reduced. A rotation should be planned and followed whereby the plants in no section will remain in the beds longer than three years. For example: If a range of several houses is divided into three separate sections—A, B, and C—all of the plants in section A should be completely torn out and replanted the first season, all those in section B the next season, and those in section C the third season. In this way the 3-year-old plants in section A would be replaced the fourth season, and so on. Several florists are now of the opinion that forcing their plants as much as possible for three years, instead of retaining them for a longer period, increases their production and more than compensates for any extra expense due to the more frequent replanting.

SUMMARY

Within the last seven years two varieties of the strawberry rootworm, *Paria canella—quadrinotata* and *gilvipes*—have appeared in greenhouses in the commercial rose-growing districts east of the Rocky Mountains and have done great injury to the rose plants. Although normally an outdoor pest on strawberry, raspberry, and a number of miscellaneous plants, this insect has become one of the serious enemies of roses grown under glass.

The plants are injured by the larvæ and adults. The larvæ feed on the roots and the adults eat foliage, stems, buds, and flowers.

The overwintering adults appear in February and lay eggs during a period of two or three months. The larvæ from these eggs feed on the roots for a period of from 33 to 74 days, after which they transform to pupæ. The adult beetles emerge from 8 to 17 days later. Because of the long period of egg-laying, the emergence of the adults during June and July is almost continuous. From the eggs which are laid by these beetles a second brood of adults develops and emerges during September and October. The two generations overlap to such an extent that oftentimes no distinctions can be noted.

Natural enemies of the strawberry leaf beetle are apparently few in the greenhouse, as no parasites have been observed attacking any of the stages. Among the predators may be mentioned carabid beetles, spiders, and toads. Uropod mites frequently attach themselves to adults.

Early experiments established the fact that the usual measures recommended for leaf-eating insects were practially useless in controlling the strawberry rootworm. Spraying with the arsenicals did not prove practical under ordinary conditions, but was found to be successful in protecting the swelling and breaking buds at the time the plants were cut back. Under similar conditions a Bordeaux-arsenate of lead mixture served as a repellent. In extensive trials the use of a 10 or 15 per cent dry mixture of arsenate of lead or calcium arsenate and superfine sulphur showed that dusting with these materials was a satisfactory and effective method of keeping the foliage coated with an arsenical to repel the beetles. Experiments with Paris green gave unsatisfactory results. In 21 commercial houses fumigation with hydrocyanic-acid gas during the resting

period of the plants consistently produced an average mortality of at least 95 per cent of all beetles above ground. Fumigation with vaporized nicotine did not kill the adults.

The effectiveness of hand picking the beetles, as practiced by many florists, may be counteracted by the overlapping of generations of this insect. It is therefore evident that to be successful hand picking must be done very thoroughly and persistently.

A modification of hand picking, wherein kerosene nicotine oleate was used to film the surface of the pools and puddles in heavily watered beds, killed any beetles which came in contact with the insecticide while struggling in the water.

Cleanliness was practiced persistently in one greenhouse and was of material assistance in reducing a heavy infestation. Immediately after cutting back the plants many adults in the soil and débris were destroyed by scraping and removing a layer of surface soil to a depth of about 2 inches, and then treating it to kill them.

Treatments of the soil with the following insecticides either failed to kill the larvæ and pupæ or were detrimental to the plants:

Acid phosphate.
Borax.
Carbon disulphide.
Hydrated lime.
Kerosene nicotine oleate.
Lye (sodium hydroxide).
Nicotine sulphate solution.
Orthodichlorobenzene.
Paradichlorobenzene.
Sodium cyanide solution.

Contact with tobacco dust, which was placed on the soil surface, killed newly hatched larvæ, and the leaching of tobacco dust and wood ashes also killed some larvæ and pupæ in the soil.

RECOMMENDATIONS FOR CONTROL

A successful control program entails a combination of several measures, since no single practice will suffice. In order to be effective such measures must be persistently followed and applied in such a manner that they will not conflict with the normal cultural program and conditions under which roses are grown.

During the summer months the protection of the plants from immediate as well as future injury is the paramount consideration. This may be accomplished by fumigating with hydrocyanic-acid gas during the drying-off period to kill as many adults as possible, and by scraping the surface soil from the beds when the plants are cut back, and then spraying them with lead arsenate or calcium arsenate, using 4 pounds to 50 gallons of water, to protect the swelling buds from the further depredations of the beetles.

From September to December *eradication* of the beetles should be the florists' aim, because they are still emerging and continue to feed voraciously for some time. Every effort should therefore be directed toward ridding the houses of as many of the overwintering beetles as possible in order to prevent a recurrence of an infestation the following spring. During this period dusting must be very thorough and continuous, in order that the foliage may be kept coated with the poison. Hydrocyanic-acid gas, however, can not be used at this time at a killing strength without causing severe injury to the plants. Two or more treatments by filming the surface water of the bed with kerosene nicotine oleate may then be most effectively used to kill many adults. Beginning about the middle of

February the plants must be kept coated with an arsenical dust to poison any beetles which may come out of hiding and resume feeding. The soil in the beds should be kept covered with a layer of tobacco dust until drying-off time, with additional applications of wood ashes at monthly intervals. The tobacco dust will kill any newly hatched larvæ which come in contact with it while crawling on or entering the soil, and the mixture of wood ashes and tobacco dust will operate to some extent against the larvæ and pupæ in the soil. To prevent the larvæ from entering the soil at an unprotected spot, it is important that the tobacco dust be spread over the entire surface of the soil in the bed.

Plants and soil should not be retained in the greenhouses longer than three years if the establishment of an infestation is to be prevented. In addition cleanliness, involving the removal of dead leaves and trash, must be practiced incessantly. Soil which is used in the beds should either be composted for several months or sterilized before being brought into the houses.

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AUTOBIOGRAPHY

I, Charles Adolph Weigel, was born in Methuen, Massachusetts, September 27, 1887. I received all of my secondary school education in the public and high schools of the city of Lawrence, Massachusetts. My undergraduate work was taken at the University of New Hampshire, from which I obtained the degree of Bachelor of Science in 1916. During the two subsequent years I was enrolled in the Graduate School of the Ohio State University and received the degree of Master of Science in 1918. While in residence at the Ohio State University I acted in the capacity of Graduate Assistant in the Department of Zoology and Entomology. During the fall and winter of 1918-1919 I served in the Sanitary Corps, Medical Department, United States Army, being stationed at the Yale Army Medical School, New Haven, Connecticut, and the Attending Surgeon's Office, Washington, D. C. After completing the work for my Master's degree I entered the employ of the Federal Horticultural Board, United States Department of Agriculture, as Entomological Inspector. In 1920 I was transferred to the Federal Bureau of Entomology and placed in charge of the "Greenhouse Insects Investigations Project." In 1922 I was advanced to the position of Associate Entomologist. I am an active member of The American Association of Economic Entomologists, The Entomological Society of America, The Entomological Society of Washington, and the Sigma Xi Fraternity. I returned to the Ohio State University in the fall of 1924 to complete the residence requirements and received the degree of Doctor of Philosophy in June, 1925.